THE HYGIENE OF Clothing

NAVMED 109

DEPARTMENT OF THE NAVY
BUREAU OF MEDICINE & SURGERY

THE HYGIENE OF
Clothing

GEORGE W. MAST
Lieutenant Commander (MC) U. S. Navy

and

HOWARD W. ENNES, Jr.
Lieutenant, junior grade, H–V(S) U. S. Naval Reserve

NAVMED 109

Division of Preventive Medicine

U.S. Bureau of Medicine and Surgery

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1943

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington, D. C. - Price 20 cents

CONTENTS

INTRODUCTION

Throughout the ages economic and political pressures, population movements, and advances in the arts of war have profoundly influenced and been influenced by clothing. The boundaries of the "civilizing" influences as well as the domination of ethnological groups were established, on the one hand by the enervating effects of heat or the restrictions of cold climates, on the other by shortened seasonal periods of food production in cold climates.

By nature a tropical animal, hairless man, by clothing himself, has been able to move progressively farther into the polar regions and to exist most efficiently in temperate zones. In fact, man's tendency has been to create, through heavy clothing and heated shelters, artificial climates comparable to tropical conditions, thus producing enervation.

Since man first wandered poleward, he sought protection from cold by converting into clothing the best materials at hand, utilizing the hair and skins of animals and experimenting with plant fibers until, by trial and error, conventional clothing was evolved. The Eskimos made parkas and pants from the skins of Arctic animals, the Mongols and Chinese fashioned robes and other garments of quilted feathers and fibers, the Russians wove long coats of wool, and western civilization produced fashionably styled, close-fitting garments in a wide variety of natural and synthetic materials. In America clothing selection has for the most part been an art rather than a science. The usual conception is that warmth and weight are synonymous. Fortunately, however, the human body is sufficiently adaptable

to wide variations in climatic conditions to permit clothing of highly diversified materials and design.

A strictly scientific approach to the selection of clothing obviously is much newer than the age-old law of self-preservation of which it is a manifestation. Today the widening scope and character of modern warfare emphasizes the necessity for reconsidering current methods of protection by clothing. Clothing for modern warfare must be functional. Not only must it afford a high degree of protection against the elements, enemy action and the contingencies of normal operations, but also it must meet the physiologic needs of the body and promote efficient physical activity.

The function of clothing may be said to be (1) the maintenance of a body environment which is conducive to the efficient carrying-out of the task at hand (with comfort, with the necessary degree of mobility, and with a minimum of unproductive fatigue), and (2) the protection of the body from heat, cold, water, fire, gas and injury. In view of this definition, it is obviously necessary in the development and practical utilization of clothing, to appreciate and be guided by the needs and problems of and the relationships between the physiologic, climatic and engineering elements involved. In brief, a comprehensive scientific approach to the problem is required. The following material emphasizes the close relationships between the several major elements involved and it is hoped may suggest some fruitful lines of further study.

CHAPTER I

THE PHYSIOLOGY OF BODY HEAT BALANCE

Heat is a vital byproduct of the living human body. By reflex physiological mechanism heat gain and heat loss are balanced. Under normal conditions the healthy body maintains a constant rectal temperature at 37° C. (98.6° F.).[1] The body regulates its temperature by varying heat production (chemical control) and by altering heat loss (physical control).

Chemical control is effected by changes in the amount of combustion going on in the cells of the body, mainly in the skeletal muscles. Some heat is generated also in the internal organs, including the heart. All the mechanical energy liberated by the cardiac muscle, however, is converted into heat within the body, for the energy of blood flow is spent in overcoming the frictional resistance of the blood vessels.

The degree of physical activity largely governs the rate of heat production in the body. When the body is in a sitting position under normal conditions of wakeful rest, heat production amounts to about 50 kilogram calories per square meter per hour. Increased muscular activity raises the temperature by 1 to 2 degrees centigrade. Moderate exercise such as walking may raise the heat production to twice the basal rate, and extremely vigorous exercise may increase it to 10 times the basal level. Under cold environmental conditions

---

[1] One or two degrees higher or lower may be normal for persons acclimatized to polar or tropic conditions. About the normal, the daily variation may amount to 1° C. (1.8° F.), being highest (37.3° C. or 99.1° F.) in the late afternoon and lowest (36.3° C. or 97.3° F.), during the early morning hours.

the body utilizes shivering, an involuntary contraction and relaxation of certain groups of muscles, to raise the rate of metabolism. During quiet sleep heat production drops 10 to 15 percent. Sleep should therefore be avoided when the body is exposed to extreme cold, since freezing and death will occur more readily. However shivering of a violent type usually prevents sleep; the majority of persons who go to sleep and die of cold are victims of a "cold stroke" not unlike a heat stroke.

The specific dynamic action of foodstuff, by processes of catabolism, frees heat. Within an hour after food is ingested heat production begins to increase, reaching a maximum of 5 to 30 percent above the basal level about the third hour and maintaining this increase for several hours. Energy release following ingestion of carbohydrates can be completely converted into mechanical work, but this is impossible in the case of proteins.

Physical control involves heat loss by conduction, radiation, convection and vaporization. It is regulated by variations in skin temperature brought about by cutaneous vasoconstriction and vasodilatation, which result in variations in the amount of blood flowing through the skin. The human body is subject to the same laws of physics dealing with heat loss as is any other body. They may be summarized as follows:

1. *Conduction* is a process by which heat is transferred primarily by direct contact. The rate of transfer depends upon the difference in temperature of the two objects considered and the conductivity of the external one. Conduction ordinarily plays but a small part in body temperature regulation.

2. *Radiation* is the transfer of energy from the body surface by means of electromagnetic waves, depends in amount upon the temperature difference between the human body and

the ambient surface, and is proportional to the surface area of the body and to its emissive power. The human body is a 97 percent "perfect black body," that is, a body which absorbs all and reflects none of the radiant energy falling on its surface. Skin color does not influence this factor. As Du Bois points out, "Man does all of his radiating at wavelengths beyond the visible, and there is certainly no difference in color between a white man and a black man in a dark room in the middle of a moonless night."

3. *Convection* is simply a mechanical process of mixing whereby a cooler fluid or gas comes in contact with a warmer fluid or gas, becomes heated by conduction and carries heat elsewhere. It is dependent upon the temperature difference between the body surface and the surrounding air and upon the rate of movement of the air over the surface of the body. The specific heat of air is a factor, especially at slow rates of air movement. This becomes of practical concern when high altitudes are involved.

4. *Vaporization* means that a definite amount of heat is required to change a given amount of liquid into vapor without changing the temperature. The change in water from a liquid to a gas involves the loss of heat from the liquid and from surrounding materials which are thereby cooled. Conversely, if a given amount of water condenses on an object, it gives to the surroundings the same amount of heat which it took from them in vaporizing.

The respiratory tract is active in the vaporization process. Air breathed in is usually cool compared with body temperature. It becomes heated more or less to body temperature while in the lungs, and thus is laden with considerable moisture when exhaled. For every gram of water thereby evaporated the body loses about 0.58 calories [2] of heat.

---

[2] All caloric values as given throughout are for kilogram calories (calories per kilogram of body weight).

The skin participates in vaporization in two respects: (1) Through insensible perspiration water is lost from the skin because of diffusion of vapor through the epidermis.

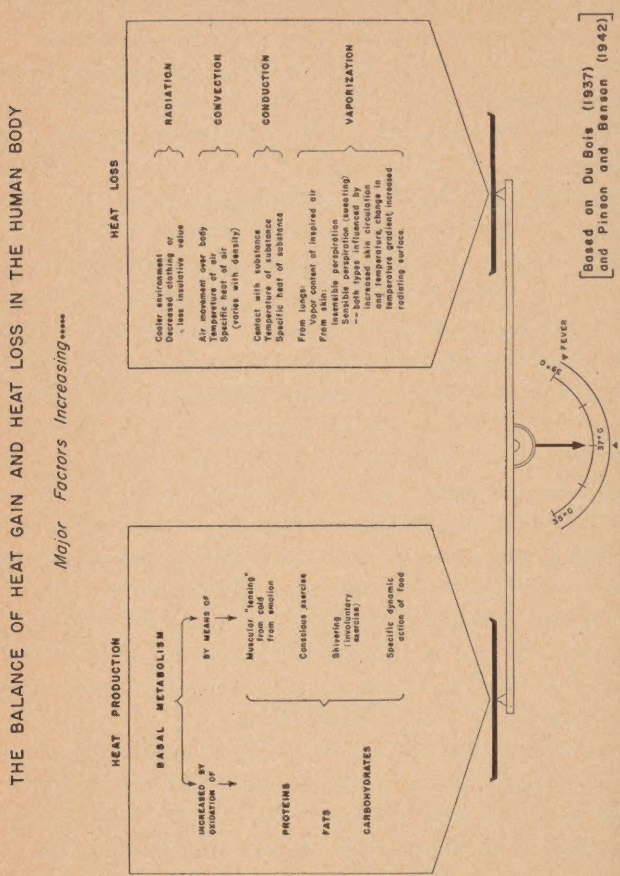


FIGURE 1.

This loss is entirely independent of the operation of sweat glands, and remains fairly constant (approximately 10 kilogram calories per hour) under varying conditions. (2) By

sensible perspiration (sweating) water is brought to the skin surface through activity of the sweat glands.

Normally the body maintains heat balance at 37° C. rectal temperature, with slight shifts throughout the day as one factor or the other predominates temporarily. Although the major elements involved in body heat balance are shown in figure 1, a number of retarding factors should also be considered. These include (1) natural protection (hair, color, texture of the skin), (2) efficiency of clothing (thickness, weight, insulative value, color, type of material, etc.), (3) living conditions (in houses, on ships, in tents, sleeping bags, etc.), (4) reduced or increased blood circulation in the skin and (5) acclimatization and the resultant changes in hemoglobin content, blood pressure and pulse rate.

On the heat production side should also be considered the effects of incoming radiation (solar, mechanical) and the changes occasioned by disease and associated fever.

Body Heat Balance in Warm Weather

Balance under warm environmental conditions, or when heat must be dissipated from the body, is maintained by increased blood flow to the surface of the body. This additional heat may be brought on by work, by exercise at ordinary temperatures, by weather conditions or by emotional and similar factors. The increased blood flow to the body surface carries more heat to the skin surface, stimulates the sweat glands to activity and raises the moisture content. Thus heat normally is lost through radiation, convection, vaporization and to a limited extent by conduction.

Perspiration and vaporization must account for most of the body heat loss under hot conditions, especially when no heat can be lost by radiation or convection, that is, when surrounding surfaces possess a higher radiation value or

555050—43——2

are warmer than the body, when air movement is at a minimum, or when the air is warmer than the body. Perspiration can lower the body temperature only when it evaporates from the body. If it evaporates from clothing it may lower the temperature of the air surrounding the body. Water of perspiration that runs off the body or is wiped off represents a loss in terms of vaporization.

If the environmental air is both hot and saturated with water, all modes of heat loss are restricted. Under this condition body temperature will rise and heat stroke result. Relative humidities of 20 to 60 percent do not affect the amount of heat lost by inactive persons. Higher humidities, however, greatly restrict the maximal rate at which heat can be lost when the environmental temperature is high and hard work is being performed. The stifling discomfort of hot air which is only moderately saturated (50 to 70 percent) is not an uncommon or pleasant experience. Fortunately the air is seldom fully saturated on a hot day and evaporization from the body can usually take place.

Heat stroke may result from disfunction of the sweat glands due to lack of water or salt in the body. The body has a comparatively small reserve supply of water and when this reserve is exhausted the body ceases to perspire. Water loss, therefore, should be replaced promptly. Thirst sensations warn of even a moderate water deficit in the body, but a salt deficit may exist without causing any undue sensation.

Salt is the chief inorganic constituent of sweat, and in addition is essential to electrolytic and nervous balance of the body. The disturbance of the salt and water balance may have extensive functional systemic effects. It is possible in a very hot climate to deplete the body of its salt content to a point where the secretion of sweat is impaired.

When sweat is secreted the loss to the body must be considered in terms of both pure water and electrolytes. The

human organism rigorously maintains osmotic equilibrium. Thus when water intake rises to a high level but only the usual amount of salt is ingested, the continued loss of electrolytes causes a progressive decrease in electrolyte content of the extracellular space. Inflowing water is not retained and in addition an amount of water corresponding to the loss of electrolytes is excreted. Consequently the volume of extracellular fluid is reduced in proportion to the net loss of electrolytes. In this event the ingestion of large amounts of water alone does not prevent the development of abnormalities such as heat cramps, serious weakness and sudden collapse.

On the other hand, when the water supply is restricted but the intake of salt continues to be relatively large, the rising concentration of extracellular fluid leads to a flow of water from the cells to the extracellular spaces. The resulting dehydration of the cells causes progressive disturbances, as intense thirst, scanty urine and increasing deterioration, culminating in hyperpyrexia and collapse.

Under most favorable practical conditions the individual should drink enough water so that his urine volume is at least 700 cc. (1½ pints) in 24 hours. The diet should contain 15 grams of salt. The drinking water may profitably be salted to the extent of 1 gram per liter, and additional salt may be obtained by swallowing enteric coated tablets.

Over a period of time individuals may become acclimatized to extreme heat. Even though the physiologic basis of this adjustment is little understood, the acclimatized individual has a real advantage. It is known that the body responds to the change by producing more sweat of a lower electrolyte concentration. Also the individual becomes less emotionally disturbed by the intensity of the climate. However, acclimatization comes about only if the individual is active. Hard work appears to hasten and increase the adjustment,

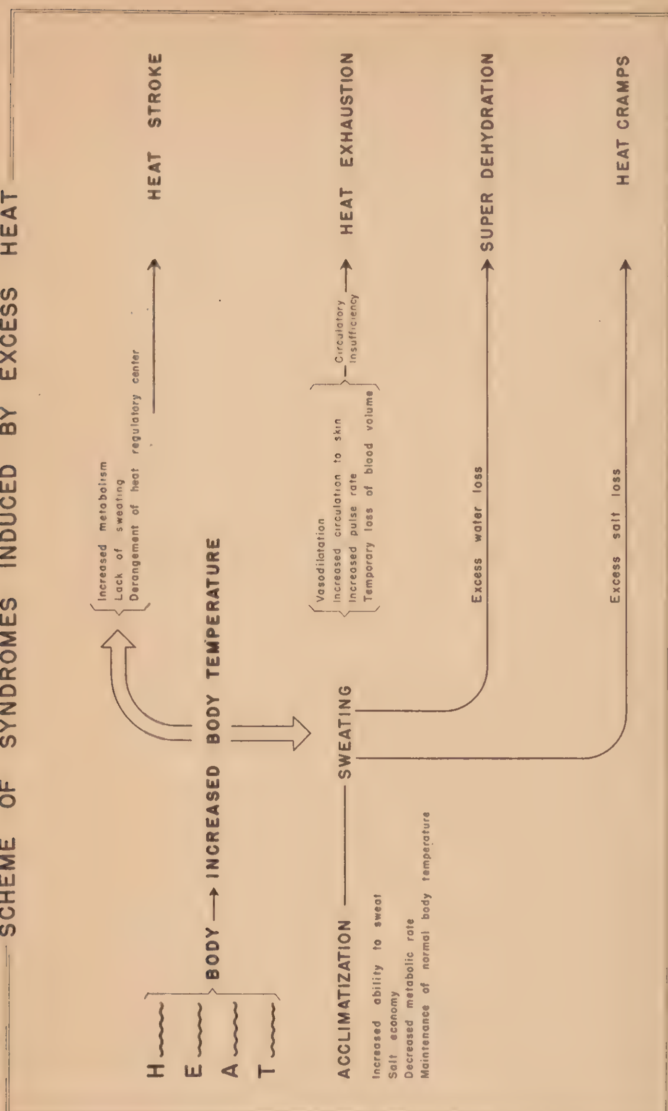


FIGURE 2.

From Behnke (1943)

which is rapid at first and may be nearly complete in a week. Acclimatization may be lost almost as rapidly as it was acquired if the individual stops working in the hot climate or leaves it.

Figure 2 summarizes the major elements involved in changes of body heat balance under warm environmental conditions.

Body Heat Balance in Cold Weather

Balance under cold environmental conditions is a problem of conservation of heat produced by the body. Sweat secretion ceases. Heat loss by vaporization is restricted to insensible perspiration through the skin and evaporation due to saturation of inspired air in the lungs.

Heat stored in the tissues of the body protects against sudden changes incurred by external cooling. Storage supplies a specific amount of heat upon demand by the atmosphere before the body itself can increase its metabolism to meet increased requirements. As the stored heat is removed the temperature of the skin drops, lessening the temperature gradient between the atmosphere and the body and thereby reducing the cooling effect of air movement.

The body has a potential heat reserve proportional to its weight in kilograms for each degree centigrade difference in air and body temperatures. The most important amount of storage is that contained in the outer layers of tissues 2 or 3 centimeters deep. For example, an average man weighing 70 kilograms (150 pounds) has a potential heat reserve of 1,890 kilogram calories when the air temperature stands at 10° C. or 50° F. However, when 5 or 10 percent of this storage has been removed from the body, pain sensations begin. This is the warning to the body of its heat deficiency. The body, taking cognizance, increases its metabolic rate by shivering.

Decreased blood flow to the skin conserves vital body heat, and at the same time the tissues, being dehydrated by this exodus of blood, become poorer conductors of heat in a ratio of approximately 1 to 4. This is most notable in the extremities. The hands and feet, especially the fingers and toes, are the best indicators of body temperature conditions. The diminished blood flow in these areas serves the essential and useful purpose of decreasing heat loss and enabling the body as a whole to maintain a heat balance. But in a sense the appendages are sacrificed, for the decreased circulation raises the minimum tolerable environmental temperature which these extremities can withstand without freezing. Actually the temperature of the unprotected foot can come down as low or lower than the environmental temperature. Freezing of inadequately protected feet may even occur without an appreciable reduction of internal body temperature.

In acclimatization to cold conditions the principal physical adjustment involves blood redistribution. An unacclimated person exposed to cold has imperfect peripheral vascular constriction, although the blood flow may continue to some extent in the periphery of the skin. The body cools more rapidly under such conditions, or at least possesses a greater pain sensation to cold stimuli.

The extremities of the unacclimatized body are supplied with greater quantities of heat. Because of this, acclimatized persons can stand the pain of cold more readily, can dress with less clothing and can therefore move with greater efficiency. Paradoxically, however, they will apparently suffer cold hands and feet more quickly than the unacclimatized person when metabolic heat production drops. On the other hand, the unacclimatized person when exposed to conditions potentially lethal will perish sooner, because the flow of heat from his body which temporarily is warming his extremities is at the same time sapping vital heat from his body.

Antarctic experience indicates that continued exposure in cold climates brings about basic changes in which the average rectal temperature drops 2 or more degrees, and basal metabolism 10 or 15 percent below normal. The body apparently has a dormant tendency toward hibernation and can exist under lowered body temperature conditions with a minimum of food intake.

Thus heat regulation of the body is a physiological function, the body being able within certain limits to compensate for changes in environmental conditions.

CHAPTER II

ATMOSPHERIC COOLING

In pioneer work in climatology Siple, through extensive practical experience in the Antarctic as well as by laboratory experimentation, developed the concept of the cooling demand of the atmosphere. Beginning with the physiological assumption that the amount of heat produced by an average healthy adult male may be predicted under various degrees of activity without emotional stress, the question turns to how this heat is dissipated into the atmosphere. The rate of cooling must be determined quantitatively in order that a value of insulation may be placed upon the amount of clothing required to maintain the body in thermal equilibrium.

The major external variant affecting the heat production of the body is what is normally termed climate. Although it has been customary to express environmental conditions affecting body heat primarily in terms of temperature, properly humidity, wind velocity, altitude and varying man-made conditions should also be considered. These conditions may be enumerated as operations on board ship, below the surface of the sea, in the air, in firerooms, in armored vehicles, and the like.

Effective Temperature

A measure of temperature in relation to body heat, which is far more significant than that offered by the ordinary dry-bulb thermometer commonly employed, is known as the "effective temperature." It takes into account humidity, is

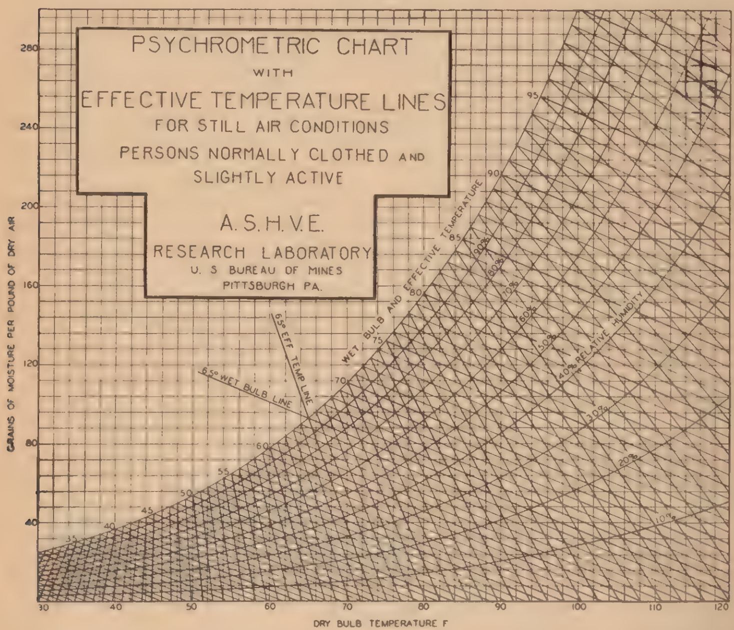
relative to air movement and is especially valuable in high environmental temperature problems. This measure has been developed over some 20 years of experimentation by the Research Laboratory of the American Society of Heating and Ventilating Engineers in cooperation with the Bureau of Mines of the U. S. Department of Interior. Figure 3 represents a standard psychrometric chart showing the thermal dynamic relationships between the moisture content and the temperature of still air, including a series of lines showing equal sensations of warmth as affected by these factors.

The dry bulb temperature (in degrees Fahrenheit) is plotted on the X-axis in figure 3 and the moisture content on the Y-axis in grains per pound of dry air. The series of lines curving upward to the right represents the relative humidity in percentage of saturation. The lines slanting obliquely to the right (parallel to line marked "65° wet-bulb line") indicate the wet-bulb temperature of the air. (Wet bulb is that temperature shown by a thermometer the bulb of which is covered with a wet wick, over which the air is moving at a high velocity.) The lines slanting just slightly to the right, running downward from the top curveline, are the effective temperature lines.

The wet-bulb reading usually is below that of the dry instrument and is the lowest temperature which may be realized by a wetted surface, due to loss of heat by evaporation. For example, on a moderate summer day when the moisture content is low, the dry-bulb temperature may read 90° F., the wet-bulb 67° F. From figure 3 the humidity is seen to be 30 percent and effective temperature 78° F. On the other hand, when humidity is high, dry-bulb temperature may be 90° F. and wet-bulb 81.5° F. Here the humidity is read at 70 percent, the effective temperature at 84.5°.

Experience has shown that this effective temperature index, particularly in hot atmospheres, is a true measure not only of a person's feeling of warmth but of many of his physiologic reactions, including changes in body temperature, pulse rate, and number of leukocytes in the blood.

The extreme range of effective temperatures which can be tolerated is between 90° and 95°. At 90° E. T. a per-



3. On this psychrometric chart, developed by the Research Laboratory of the American Society of Heating and Ventilating Engineers, are plotted effective temperature lines for still-air conditions. On the *Y*-axis are moisture content values, with the up-curving lines representing relative humidity. The point of intersection of the dry-bulb temperature in degrees Fahrenheit (*X*-axis) and the wet bulb temperature indicates the effective temperature value as located by the lines sloping sharply downward.

son seated at rest will not maintain temperature equilibrium, but will experience a rise in body temperature of about 1° F. per hour. The 90° E. T. may cover a range from 91° F. dry-bulb and 95 percent relative humidity to 124° F. at 10 percent humidity. Body temperature increases radically at 90° E. T., and at 95° E. T. the limit of human endurance is normally reached, at least for periods of 3 hours or more.

Dry Cooling

In adapting clothing to cold climates, it is desirable to eliminate unnecessary cooling by vaporization. Profuse perspiration is not only a nuisance, but a real danger in that clothing remains damp and the cooling effect continues long after the cause for it is past. Unavoidable vaporization losses (by sweating) may normally account for about 10, but sometimes as much as 25 calories of total cooling per hour. Beyond this, however, all external means of cooling under cold conditions are by dry cooling, including radiation, convection and conduction.

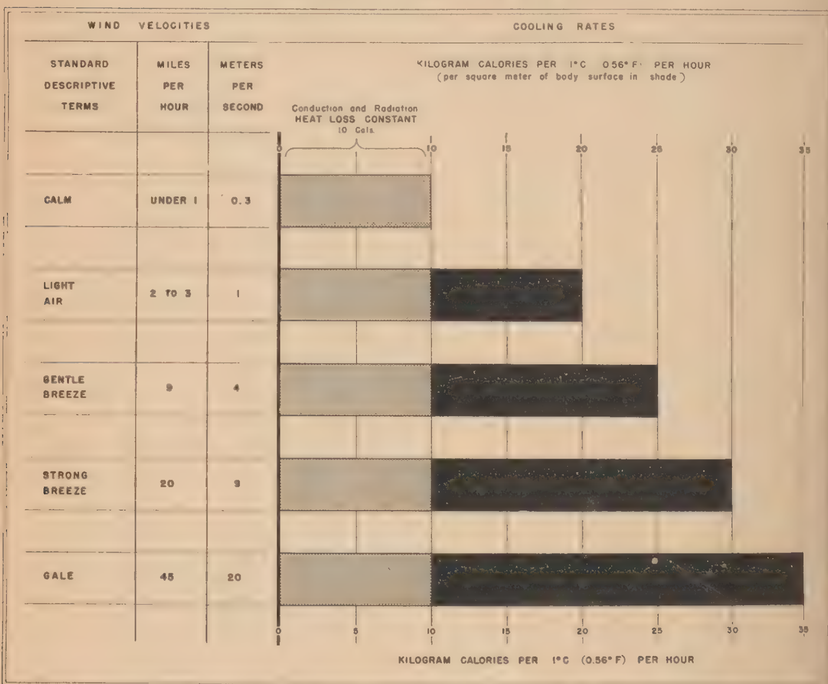
Recent experiments showed that under conditions of still air the minimum rate of heat loss by a small body (equal in volume to the exposed portions of the face or the extremities) varied between 7 and 10 kilogram calories per square meter of exposed surface per hour and per degree centigrade. Moving air causes a sharp rise in this cooling rate, reaching an average value of 23.15 calories when the wind velocity rises to 5 miles per hour. The rate of increase becomes less as the wind attains a velocity of approximately 15.9 miles per hour, at which point cooling reaches 30 kilogram calories per square meter of exposed surface per hour and per degree centigrade.

For all practical purposes the maximum cooling due to increases in wind seldom exceeds 35 calories at velocities

above 45 miles per hour. Previously it has been noted that at all times approximately 10 kilogram calories are lost by radiation and conduction. Figure 4 summarizes these data relative to dry-shade cooling at varying wind velocities.

A formula based on these studies has been developed by

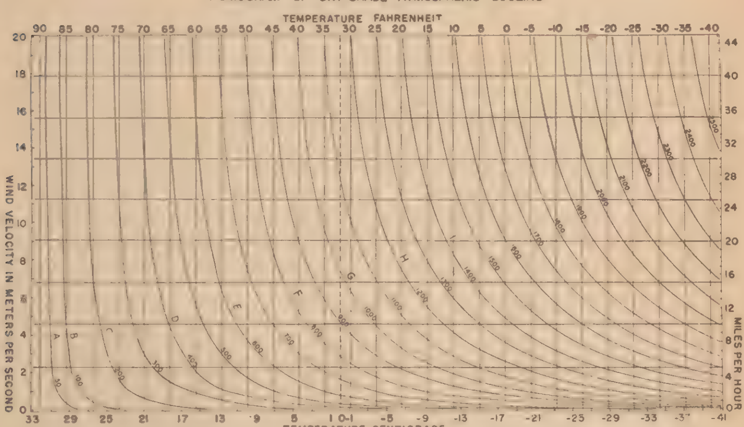
SUMMARY OF DRY SHADE COOLING RATES OF THE ATMOSPHERE AT DIFFERENT WIND VELOCITIES OUT OF DOORS



4. Cooling progresses downward from a value of 0.0 at 33° C. (91.4° F.) which is neutral skin temperature just below the sweating point. A constant loss of approximately 10 kilogram calories per 1 degree centigrade per hour is attributed to insensible perspiration. Maximum cooling due to increases in wind velocity are about 35 calories at velocities exceeding 45 miles per hour.

Siple and Passell (*23*) to estimate the total cooling effect of the atmosphere. It evaluates dry-shade cooling in kilogram calories per square meter of body surface per hour, using insensible perspiration loss as the constant, and giving wind velocity in meters per second and air temperature in degrees centigrade. Since primary concern is with climatic cooling of the body for optimal comfort, the logical basis for a cooling scale is with the zero point at 33° C. (91.4° F.), the point at which the skin normally is in comfortable thermal equilibrium.

NOMOGRAM OF DRY-SHADE ATMOSPHERIC COOLING



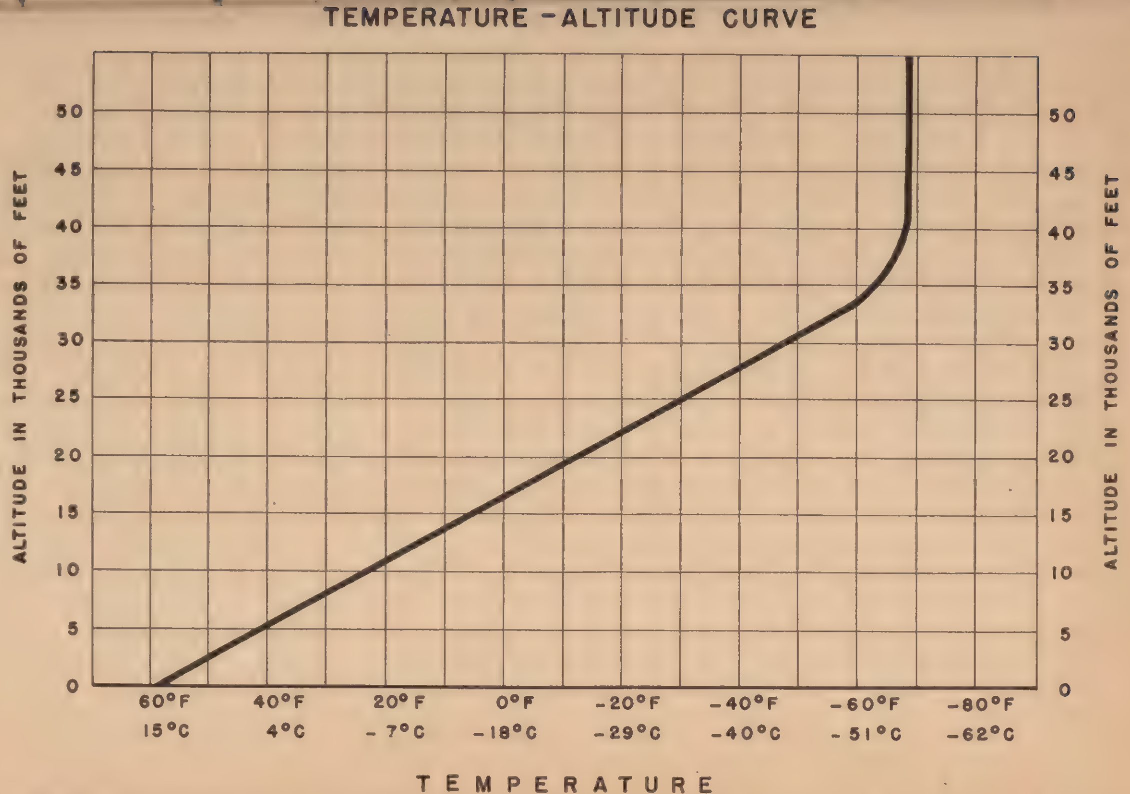
5. Cooling is expressed in kilogram calories per square meter per hour for various temperatures and wind velocities. The cooling rate is based upon a body at a neutral skin temperature of 33° C. (91.4° F.) when the dry cooling rate is less than the rate of body heat production, and excess heat is removed by vaporization. Under conditions of bright sunshine cooling is reduced by about 200 calories. Cooling lines, indicated by the letters *A*, *B*, *C*, etc., express relative comfort zones for an individual in a state of inactivity as follows: *A*, hot; *B*, warm; *C*, pleasant; *D*, cool; *E*, very cool; *F*, cold; *G*, very cold; *H*, bitterly cold; *I*, exposed flesh freezes.

From this formula the nomogram, shown in figure 5, was constructed. It enables quick determination of the caloric cooling value for any set of temperature and wind velocity points. Thus, with a gentle breeze (about 9 miles per hour) and with the temperature at 35° F., the dry-shade atmosphere cooling value would stand roughly at 825 kilogram calories or definitely "cold." An increase in wind velocity to that of a strong breeze (above 20 miles per hour) would raise the cooling value for the unprotected body another 175 kilogram calories to the "very cold" range. A temperature drop of about 12° F. would have the same effect. Under conditions of even a moderately strong breeze (15 miles per hour) and with the thermometer at 20° F., cooling would reach 1,200 kilogram calories, considered "bitterly cold."

Two natural boundaries limit the extreme rate at which the body can be cooled: (1) When cooling exceeds 1,200 kilogram calories, causing human flesh to freeze upon relatively short exposure—if the cooling rate reaches 2,000 kilogram calories the exposed face will begin to freeze within 1 minute. (2) When the air temperature drops to between minus 50° and 60° F.—then exercise no greater than fast walking, occasioning deep breathing, may cause hemorrhage in the bronchial tubes. Cooling to this extent probably approaches 1,000 to 1,500 calories, and frosting of delicate tube tissues results.

Air density is another cooling variable. Dense, moisture-laden air reduces radiation by conducting heat more readily. Rarefied air on the other hand increases radiation, incoming or outgoing. Dead air may be considered a fair nonconductor, particularly in very small spaces.

Altitude inhibits the body's ability to react normally. Variation in altitude affects air pressure, availability of oxygen and the thermal gradient. The limit to which altitude permits normal body functioning without demanding



6. "Standard air" having a temperature of 15° C. at sea level is assumed. The slope of the curve would be essentially the same for any other temperature.

extra oxygen is about 18,000 feet. The body is affected in its metabolic processes by variations in the amounts of carbon dioxide in the air. Respiration is increased and circulation stimulated. As altitude increases, the temperature drops at a rate of approximately 3° F. per 1,000 feet. When an altitude of 35,000 to 40,0 0 feet is reached, the temperature remains at about minus 67° F. (fig. 6).

Associated Variable Factors

Under practical conditions cooling is composed of many variable factors in addition to those already discussed. These factors may widely deflect cooling values from the average. For example, the formula is based on outgoing radiation: in daylight considerable heat may be absorbed by the body, even though light-colored clothing reflects 45 to 70 percent of the solar radiation. Clouds reduce the heating efficiency of the sun's rays, but a snowfield may diffuse or intensify it. Bright sunlight seems equal to about 200 kilogram calories per square meter per hour, dropping to half that value when thin clouds are present. When calculating cooling, therefore, the estimated amount of solar radiation is subtracted from the dry-shade cooling value as indicated in figure 5.

Atmospheric cooling-demand calculations produce, it must be kept in mind, a value for climatic cooling stress on a naked human body under optimal comfort conditions. Thus the amount of body heat involved under varying circumstances of activity and food intake is of major importance in the ultimate determination of the clothing insulation required to maintain body efficiency.

Numerous variables also enter into body heat production. Unconscious tensing of muscles and shivering have been mentioned. They may increase body heat substantially, although

the effect on the individual is decidedly unpleasant. The emotions, especially fear, also affect the heat output of the body. Closely associated with other forms of body activity, emotion is apparently capable of increasing the heat output of the body by as much as 200 to 300 kilogram calories, even more under extreme circumstances. Fatigue is an important negative factor in heat production. Illness may disrupt the entire body-heat balance mechanism by preventing relief from fever by perspiration. Injury may alter local thermal output. Basal metabolism varies also with age and sex.

TABLE 1. *Heat Production at Varying Conditions of Body Activity*[1]

Condition of activity	Heat production	
	met	Cal./M²/Hr.
Sleeping	0. 8	40
Sitting at rest	1. 0	50
Standing	1. 5	75
Slow level walking	2. 0	100
Normal level walking	3. 0	150
Fast level walking	4. 0	200
Average maximum sustained heavy work	5. 0	250
Short periods of heavy activity	10. 0	500

[1] After Herrington, 1941; Gagge, Burton, and Bazett, 1941; Siple, 1942.

It has been previously noted that when the body is at rest in a sitting position heat production amounts to about 50 kilogram calories per hour. This has been taken as a working standard for minimum heat production and referred to as a "met". A "met" of heat is about equivalent to the heat generated by a 100-watt electric light bulb. As body activity increases, heat production also rises. Table 1 shows relative heat production at varying degrees of activity.

The quantity, quality, digestibility and caloric content of food greatly affect body heat production. The amount of

work in relation to food intake can be estimated and the daily nutritional requirements approximately determined. For example, let us take the case of a man doing 3 mets of work. His body surface[1] (1.9 square meters) multiplied by 3 mets (150 kilogram calories per square meter per hour) equals 285 calories per hour. Then:

	Food required (calories)
If he works 8 hours at 285 cal	2,280
If he sleeps 8 hours at 1.9 sq. M. × 40 cal	608
If he rests and stands 8 hours at 1.9 sq. M. × 60 cal	912
His total daily work produced or daily usable food required is	3,800

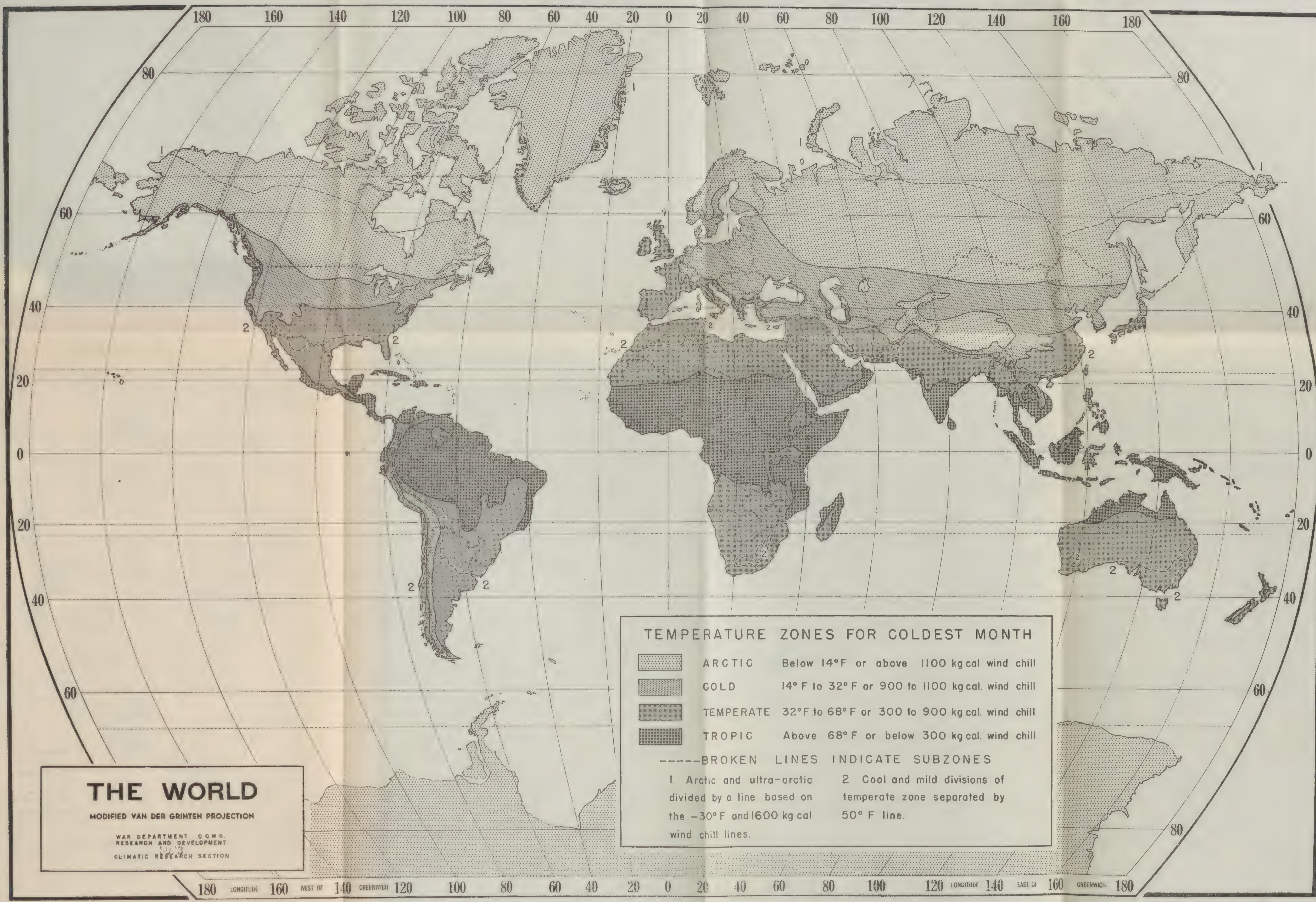
These figures of course are subject to many variations.

Mean Cooling Maps

A new concept of climate data in relation to clothing is being developed by Siple and the Army Climatic Research Section in the form of cooling maps. The insert is a world map of temperature zones for the coldest month. Figures 7 and 8 are sample representations of the North American continent in midwinter and midsummer. Wind-chill values in terms of kilogram calories per square meter per hour are indicated by iso-cooling lines on the continental maps and on the world map by heavy lines and shaded areas.

These maps are constructed on the basis of average monthly temperatures and wind velocities in terms of the formula

[1] The total quantity of heat produced by an individual is in proportion to his size. However, as the surface of the body increases with his size, a rough ratio of heat per square area of surface is used as a means of averaging metabolic output of individuals of all sizes and shapes. The common measure used here is the ratio of heat production by the body to a square meter of body surface in 1 hour. Due to the discrepancies in surface area between a fat and a slim man, certain anomalies are present in which we must expect cooling to be greater for the thin person than for the fat.



TEMPERATURE ZONES FOR COLDEST MONTH
ARCTIC Below 14°F or above 1100 kg cal wind chill
COLD 14°F to 32°F or 900 to 1100 kg cal. wind chill
TEMPERATE 32°F to 68°F or 300 to 900 kg cal. wind chill
TROPIC Above 68°F or below 300 kg cal. wind chill
-----BROKEN LINES INDICATE SUBZONES
1. Arctic and ultra-arctic divided by a line based on the -30°F and 1600 kg cal wind chill lines.
2 Cool and mild divisions of temperate zone separated by 50° F line.
THE WORLD
MODIFIED VAN DER GRINTEN PROJECTION
WAR DEPARTMENT O.Q.M.G.
RESEARCH AND DEVELOPMENT
CLIMATIC RESEARCH SECTION
LONGITUDE WEST OF GREENWICH
LONGITUDE EAST OF GREENWICH

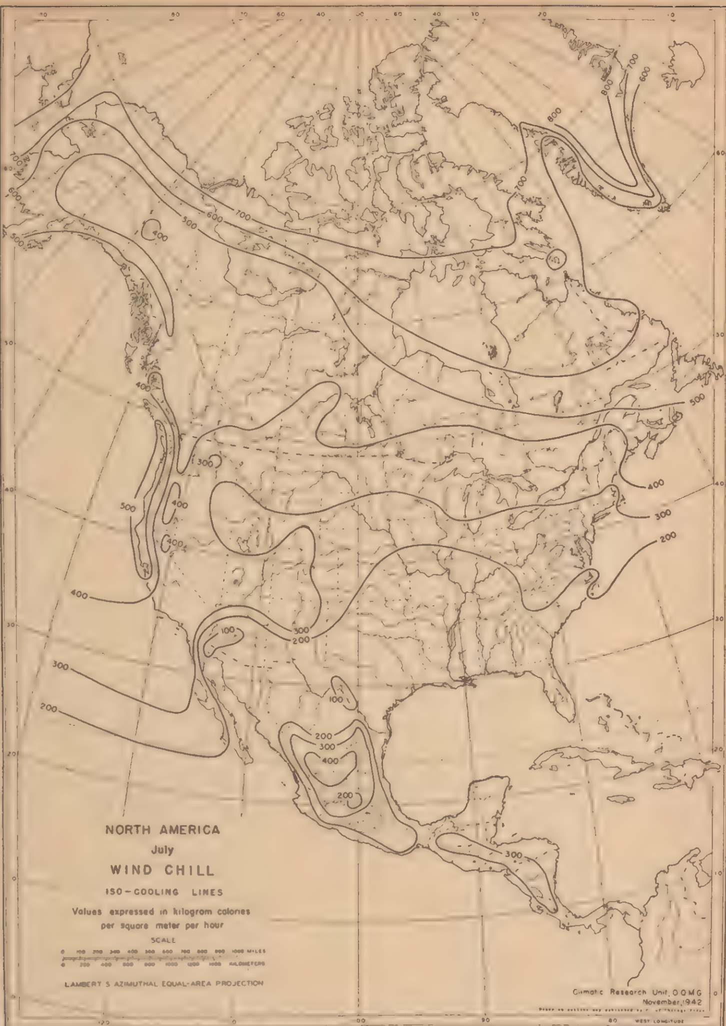
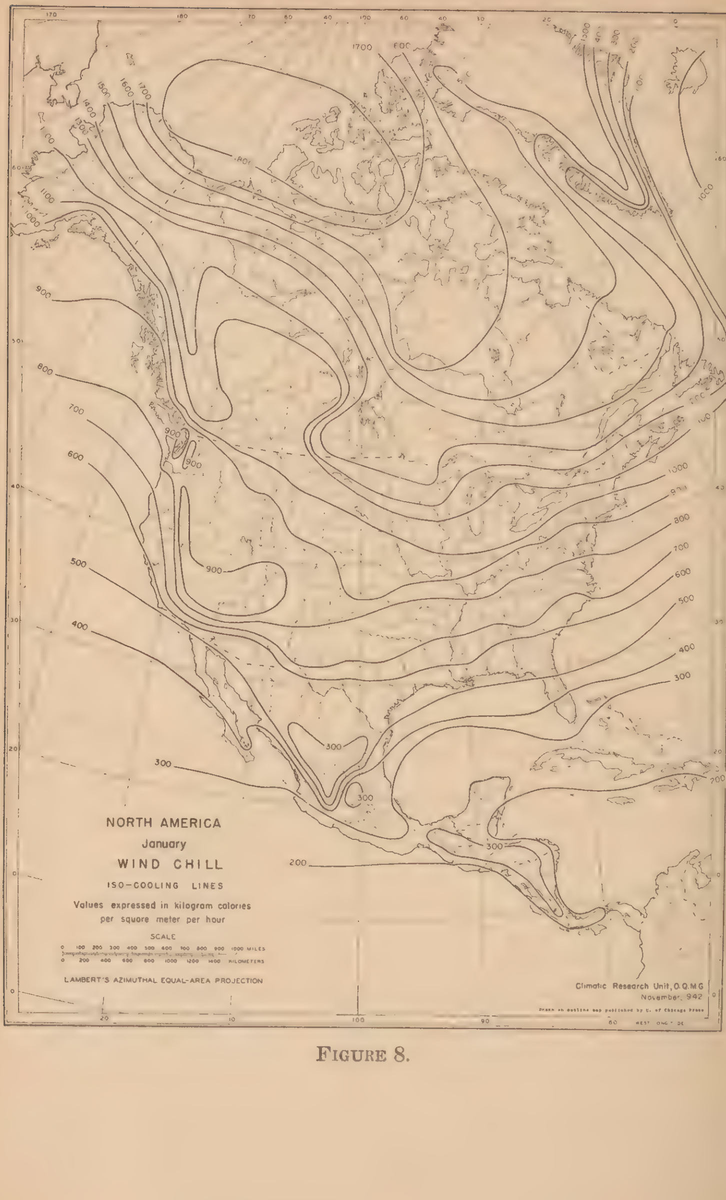

NORTH AMERICA
July
WIND CHILL
ISO-COOLING LINES
Values expressed in kilogram calories per square meter per hour
SCALE
LAMBERT'S AZIMUTHAL EQUAL-AREA PROJECTION
Climatic Research Unit, O.Q.M.G.
November, 1942
WEST LONGITUDE

Figure 7.



NORTH AMERICA
January
WIND CHILL
ISO-COOLING LINES
Values expressed in kilogram calories per square meter per hour
SCALE
LAMBERT'S AZIMUTHAL EQUAL-AREA PROJECTION
Climatic Research Unit, O.Q.M.G

FIGURE 8.

upon which the Dry-Shade Atmosphere-Cooling Nomogram (fig. 5) is based. By means of such maps, this new concept of the rate of cooling can be used directly to determine the probable degree of stress that a given geographical region would place upon a naked human body.

The data here presented are considerably at variance with popular notions of climate which are largely based on temperature, somewhat tempered by humidity considerations and to a minor extent by air currents. The two sample maps show the shift in cooling bands between summer and winter. Such data, refined and elaborated upon, may prove of substantial value in military strategy.

On the July map (fig. 7) it will be noted that the 300–400 band covers much of New England and the northern portions of the United States—as well as substantial sections of southern California and neighboring States. In January (fig. 8) this 300–400 cooling band has shifted so far south it touches only the tip of Florida and lower Mexico. The 700–800 band which in January covers Norfolk and extends through the lower third of the country, in July covers the northernmost portions of Canada. The coastal area of Alaska in January is no colder, in terms of atmospheric cooling, than much of West-Central United States or the Manhattan area and is warmer than Chicago.

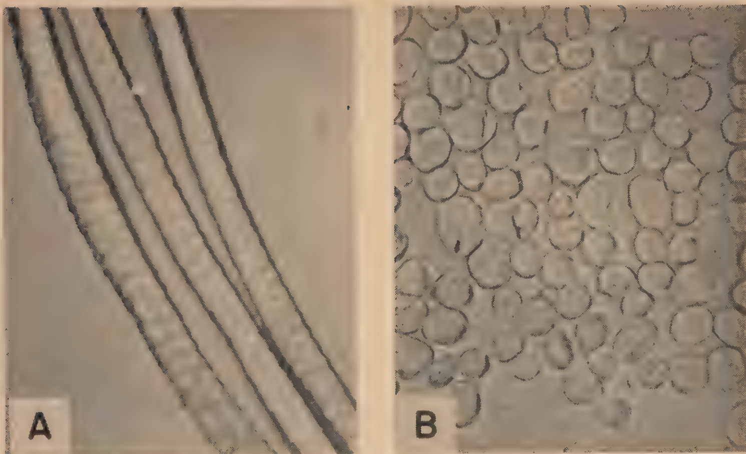
CHAPTER III

THERMALDYNAMIC ASPECTS OF TEXTILES

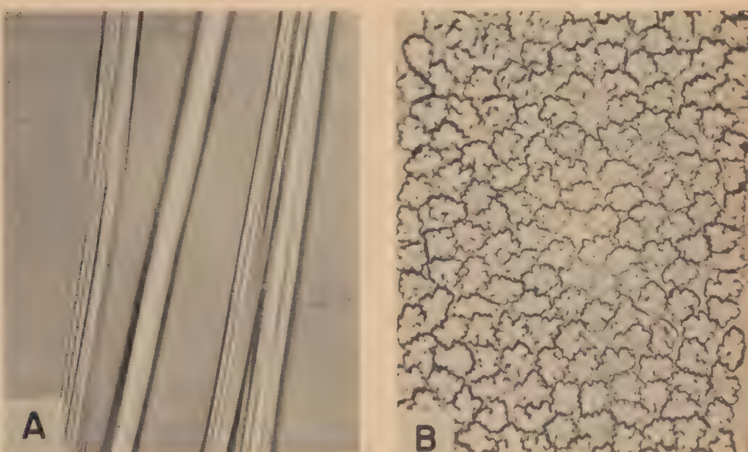
Textile fibers in most common use are cotton, wool and rayon. They differ in suitability for a purpose depending upon (1) their physical properties, as fineness, strength, elasticity, resilience, moisture content, (2) their sensitivity to chemicals such as cleaning compounds, and (3) their susceptibility to organisms such as fungi, bacteria and insects.

All textile fibers contain moisture, the amount varying with the humidity of the air. At 65 percent relative humidity cotton has a moisture content of about 8.5 percent. Cotton is stronger wet than dry, wool is little affected, wet rayon is very much weaker. Both wool and cotton have good elasticity; rayon does not. Wool is more resilient than either cotton or rayon.

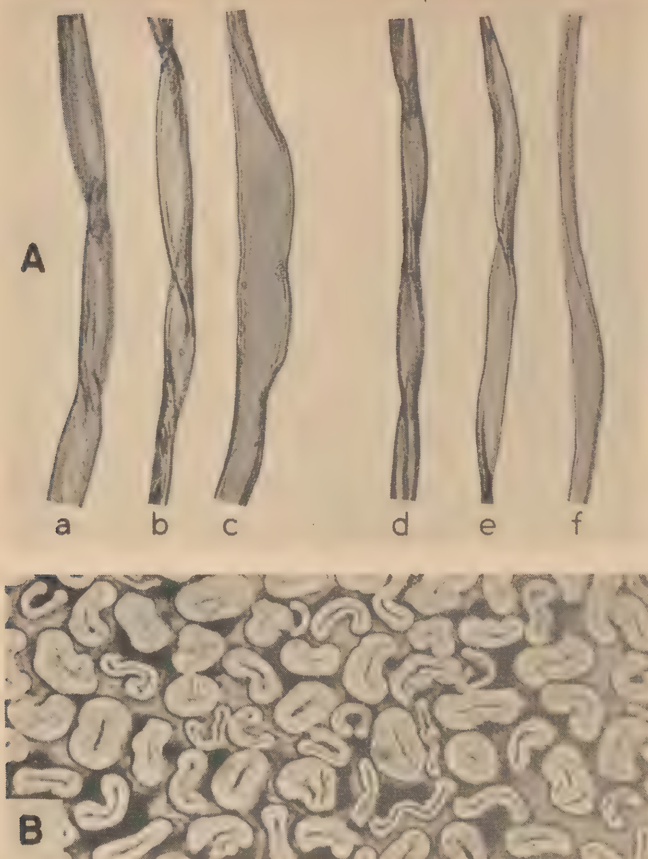
Wool is extremely sensitive to alkalies. It dissolves in hot caustic soda. Cotton dissolves in concentrated acid. Mercerized cotton, the product made by treating cotton with strong caustic soda, is characterized by its high luster and increased strength. Wool, rayon and cotton are all attacked by bacteria and fungi if left in a warm, moist condition. In addition wool is susceptible to attack by clothes moths and carpet beetles. Long exposure to direct sunlight also will damage all three types of fibers. In general wool textiles feel soft and warm to the touch and because of natural resilience tend to hold their shape better. Cotton is the fabric of choice if repeated laundering is necessary. Figures 9, 10 and 11 are photomicrographs of the three fibers.



9. Photomicrographs of wool fibers. *A*—Longitudinal view. *B*—Cross section. × 125. (From National Bureau of Standards, U. S. Department of Commerce.)



10. Photomicrographs of rayon fibers. *A*—Longitudinal view. *B*—Cross section. × 125. (From National Bureau of Standards, U. S. Department of Commerce.)



11. Photomicrographs of cotton fibers. *A—Specimen a*, thick, *specimen b*, medium and *specimen c*, thin-walled fibers from an American upland coarse cotton. *Specimen d*, thick, *specimen e*, medium and *specimen f*, thin-walled fibers from an American upland fine cotton, staple length $1\frac{3}{8}$ inches. × 237. *B*—Cross section of American upland cotton fibers. × 500. (Photomicrographs from Agricultural Marketing Administration, U. S. Department of Agriculture.)

The thermal insulation afforded by a fabric is more dependent upon the thickness (not weight) of the fabric than upon the kind of fiber. Weight does not necessarily imply warmth. Cotton, wool, and rayon, made into fabrics of the same thickness and of similar weave, afford relatively the same thermal insulation, but animal and vegetable fibers do vary in their rate of conductivity. Feather eiderdown, for example, appears to have a thermal conductivity less than that of air itself and usually is regarded as the warmest of all clothing material. Wool, however, is particularly suitable for making thick fabrics of low density. Such fabrics contain large amounts of enmeshed air and accordingly have high resistance to the passage of heat. This is so because while dead air may be considered a fair nonconductor of heat, it is so easily set in motion by convection currents that, unless it is confined in very small spaces, it becomes an effective cooling agent.

Thin, open-weave fabrics are cool because they allow the free circulation of air. Wool fabric as thick as medium-weight felt will transmit about 3 kilogram calories of heat through a square meter of fabric 1 centimeter thick in 1 hour per degree centigrade difference in temperature. Cotton of equal density and thickness will transmit 3.7 kilogram calories, and linen, 9.

Heat storage in garments is comparable to heat storage in the skin. Storage varies in accordance with the bulk and density of the cloth. The thicker the garment the wider will be the temperature gradient between the atmosphere and the individual. Heat storage is therefore greater in a thick garment. This factor is important for hand and foot protection and for sleeping bags. Fabrics also vary in efficiency as they age; when they become thinner, thermal insulation decreases. So also the state of cleanliness of a

555050—43——5

fabric alters its efficiency; dirty, greasy, sweat-soaked garments will conduct heat more rapidly.

Fabrics differ substantially in their ability to absorb or transmit moisture. It is essential, therefore, especially in cold weather, that both sensible and insensible perspiration be allowed to evaporate. A dry garment, before it comes into hygroscopic equilibrium with the body and atmosphere, will absorb insensible perspiration from the body to the extent of cancelling the normal 10 percent heat loss from this source.

In fact, garments having a lower relative humidity than the atmosphere will attempt to absorb moisture, thereby increasing their temperature due to heat released by condensation. This absorption usually occurs within the first or second hour. Thus wool garments, and some others, not only serve as insulators but as minor heat producers—to as much as 10 degrees when the relative humidity rises to 50 percent above the original humidity of the garment.

In the development of adequate clothing for cold climates the insulation of body heat and the air permeability of fabrics are of chief importance. Although a fabric may be warmer when it is least dense, it is usually more permeable to air, with any slight air movement carrying away the dead-air insulation within the fabric and raising the temperature gradient. As insulation against moving air it is desirable to construct a wind baffle, one which can effectively reduce heat loss from the body by as much as 50 to 75 percent under conditions of strong winds.

An ideal fabric for a windbreak is one with sufficient density to permit only a minimum of air to pass through it. At the same time, however, it must not be absolutely airtight, as it must be able to transmit to the atmosphere the vapor of insensible body perspiration. Such fabrics of course are of little value as insulators.

TABLE 2.—*Thermaldynamic Properties of Fabrics*[1]

Type of fabric	Grade of materials	Weight (oz. per sq. yd.)	Thickness (inches)	Index of air permeability	H Thermal conductivity (Cal. / M^2/ Hr.) per-cent	$\frac{1}{H}$ Insulation value
1 Poplin (cotton) wind resistant	Cotton	8.9	.0160	97.	88.2	.043
2 Cloth (cotton) khaki, 8.2 oz. twill Zelan	Cotton	8.2	.0210	45.	72.0	.0139
3 Flannel shirting, 10½ oz	80% wool 20% cotton	7.3	.0312	13.8	38.2	.0262
4 Cloth, serge, 18 oz	64's	12.5	.0383	41.7	35.3	.0265
5 Blanket, 3¾ lb	56 to 60's	15.1	.1376	6.8	9.4	.1060
6 Overcoating, Melton, 32 oz	55% 44's, 10% 58's 35% R. W.	22.8	.1068	26.1	12.56	.0772
7 Underwear fabric, light wool	50% wool, 50% cotton	11.7	.0660	6.0	21.6	.0462
8 Underwear fabric, heavy wool	85% wool, 15% cotton	16.2	.0950	5.0	14.4	.0694
9 Shearling			.375		3.1	.327

[1] Data from the Philadelphia Quartermaster Depot, U. S. Army, except for conduction and insulation figures which were calculated by the Leeds formula in "General Principles Governing Proper Selection of Clothing for Cold Climates as Related to the Human Body, Climate and Textiles" Paul A. Siple, War Department Standardization Branch, O. Q. M. G., 1941.

The per centimeter heat conductance values of wool, cotton and linen have been noted, but this estimation is impractical. It is more desirable to make the measurement of heat transmission for the actual thickness of the cloth itself. This is usually referred to as the "thermal conductance" of the fabric, and may be calculated by a formula devised by the University of Leeds Textile Laboratory.

Since garments consist of several layers of cloth of various sizes and shapes, the total thermal conductance of the garment may vary sharply from the combined values of the original textiles. Further, the conductance values of layers of cloth cannot simply be added together to give the combined conductance. With the additional thickness and air spaces, thermal conductivity is reduced. Siple has introduced the term "insulation value" $(\frac{1}{H})$ to express these reciprocals of conductivity.

The modified Leeds formula gives the "insulation value" of a fabric as follows:

$$\frac{1}{H} = \frac{16 + (801 - 631\Delta)\,d}{15}$$

Where: H = thermal conductivity in gram calories per square centimeter per degree per second.
Δ = density in grams.
d = thickness in centimeters.

Table 2 contains data relative to air permeability, thermal conductance (H) and insulation value $(\frac{1}{H})$ for 10 types of fabrics commonly employed in the manufacture of "warm" clothing.

CHAPTER IV

INSULATION VALUES OF CLOTHING

Some valuable comparisons may be drawn from a study of table 2. For example, although the blanket (item 5) is almost 30 percent lighter than the overcoating (item 6), it nevertheless has an insulation value 1.4 times that of the overcoating. However, protection in moving air is almost negligible because the blanket is four times more permeable to air than the overcoating.

If, on the other hand, poplin (item 1) is used as a "shell" or covering over the blanket, the combined weight approaches that of the overcoating, but its insulation value in still air doubles. In moving air its resistance is nearly 3.75 times as great as the overcoating. By careful selection of materials and combinations of materials, therefore, the insulation value of clothing can be increased markedly without adding weight. Militating against this substantial advantage, however, is the fact that lightweight garments with high insulation values are almost always more bulky and usually less durable. Durability can be increased by the use of an outside layer or shell of some material such as tough cotton. Bulky garments also permit greater storage of heat, thereby broadening the zone of steep temperature into which an individual may safely venture in very cold climates.

The insulation values of clothing fabrics can be estimated by formula and closely approximated by laboratory test. Obviously, therefore, a method can be devised for determining the amount of clothing insulation required for a given atmospheric condition.

Siple's scheme takes into account the atmospheric-cooling demand, body-heat production, solar radiation and the difference between skin and atmospheric temperature. His formula gives a value for the insulation resistance (Cl_r) offered by clothing:

$$Cl_r = \frac{K_o - (M + S - E + R)}{T_s - T_a}$$

The formula is broken down as follows:

K_o = Atmospheric cooling demand (from figure 5).

M = Metabolic heat output.

S = Positive storage; i. e., heat which can be removed from the outer tissue and which can be calculated by the formula S–15 $(33-T_s)$.

E = Evaporation losses usually equal to approximately 24 percent of the heat loss from insensible perspiration and from respiration when the body is at rest.

R = Solar radiation which approximates 200 Calories in bright sunshine, 100 Calories in light cloud, and no Calories under conditions of shade or thick cloud.

T_s = Temperature of skin ° C. (T_s may be estimated if storage (S) is known by the formula $T=33-\frac{S}{15}$).

T_a = Temperature of air in ° C.

A convenient method for visualizing the insulative value of clothing has been developed by Gagge, Burton, and Bazett (*9*). They use the term "clo" to describe the insulation value of a garment that is required to keep the body in comfortable thermal equilibrium without the need for heat storage. This is calculated with the skin temperature remaining at 33° C. in a room with a temperature of 70° F. (21° C.), an air velocity of approximately 20 feet per minute and a relative humidity of 50 percent. Their formula for the insulation value of a garment is:

$$1 \text{ clo} = \frac{.18 \times {}^\circ\text{C.}}{\text{Cal./M}^2\text{/Hr.}}$$

For normal outdoor conditions where air movement is less than 1 mile per hour the same conditions at 70° F. would require 1.5 clo of insulation. Siple's Cl_r value for a calm condition is based on outdoor air which is moving at a velocity under 1 mile an hour. Thus the Cl_r per degree centigrade difference between air and skin temperature is equal to a value of 1.5 clo. One clo therefore equals 60 kilogram calories of thermal resistance.

CHAPTER V

DETERMINATION OF CLOTHING REQUIREMENTS

The several variable factors involved in the development of efficient clothing do not operate separately. Physiologic factors affect the operation of the laws of physics, the properties of textiles and the influence of climate. Each in turn influences the other and affects the functioning of the body. Clothing requirements depend upon the interaction of physiologic and climatic factors. Figure 12 correlates these factors and permits rapid calculation of insulation needs. Here is shown the wide range of factors which have so far been considered:

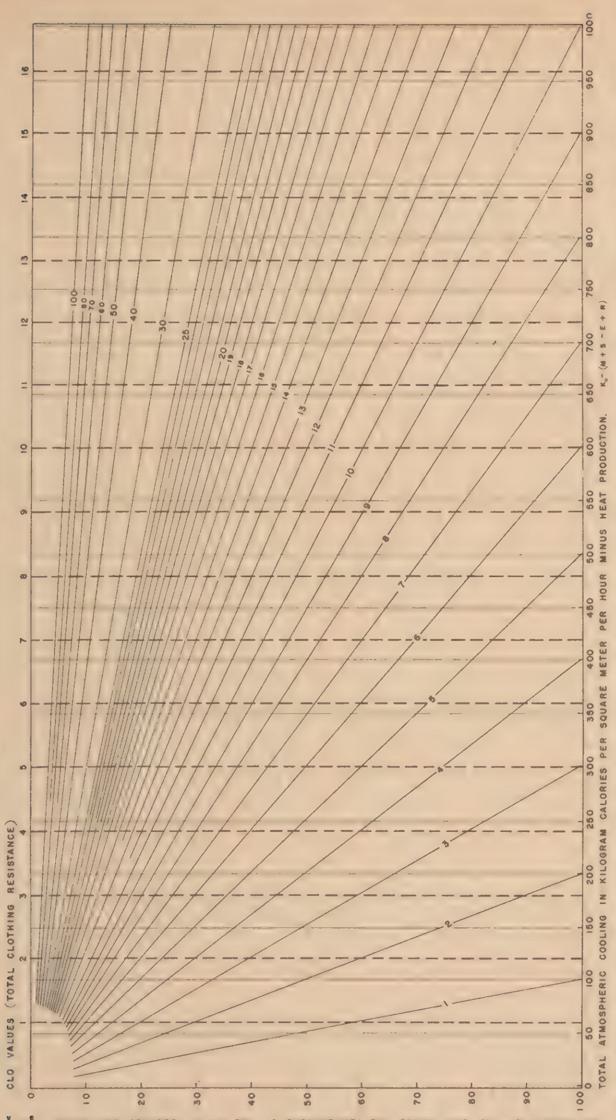
1. Physiologic and related factors—body heat balance, storage, physical activity and the like.

2. Climatic demands—air temperature, wind velocity, solar radiation.

3. Textile properties—fabric characteristics, wind resistance, insulation values.

On the X-axis is plotted (1) the total atmospheric cooling previously described and (2) body heat production, taking into account metabolic heat output, positive storage, evaporation losses and solar radiation $(M+S-E+R)$. On the Y-axis is plotted the temperature of the skin minus the temperature of the air.

The diagonal lines represent the resistance in kilogram calories (Cl_r) offered by clothing for each degree of difference between skin and air temperature. In other words, they represent essentially the straight-line relationship between



12. Diagonal lines represent the resistance in kilogram calories offered by clothing for each degree difference between skin and air temperature. The heavy vertical broken lines represent total clothing resistance in terms of clo (60 Cl_r units). Siple, 1942.

the temperature difference and atmospheric-cooling body-heat factors. The vertical broken lines represent total clothing resistance in clo units.

From this nomogram, therefore, clothing requirements may be at least roughly calculated for practical needs. For example, let us say that an estimation of clothing requirements for January in Anchorage, Alaska is desired. The following steps would comprise this calculation:[1]

1. On the North American Wind-Chill Map for January (fig. 8), Anchorage is seen to lie between iso-cooling lines, with values of 900 to 1,000 calories. For practical purposes this spot may be considered as having a cooling value of 1,000 calories, or "very cold."

2. Body-heat production is then estimated from table 1. We assume "normal, level walking" to be the condition imposed. This produces 150 kilogram calories per square meter of body surface per hour.

3. Next, by subtracting heat production (150 Cal.) and the factor of solar radiation under conditions of thin clouds (100 Cal.) from the mean cooling value (1,000 Cal.), the horizontal scale point on the Nomogram for Computing Clothing Requirements (fig. 12) is determined at 750.

4. From skin temperature in degrees centigrade (33° C.) is subtracted the mean air temperature for Anchorage in January (11.2° F. or minus 11.5° C.). This establishes the vertical scale point at 44.5° C.

5. Following the 750 calories diagonal line to its point of intersection with the 44.5° C. temperature line, the clo insulation value, as read from the vertical broken line at the top of the nomogram, is found to be 5.75 units.

[1] The calculations in these examples have been simplified by disregarding the factors of positive storage and evaporation loss, and no specific consideration has been given to food intake.

For comparison a similar calculation may be made for Anchorage during the month of July when the mean temperature is 57° F. (13.9° C.):

1. Atmospheric cooling, as read from the July Wind-Chill Map (fig. 7) is 500 calories.

2. Body heat production remains at 150 calories.

3. Subtracting body heat production and the solar radiation factor (100 calories as before) from the mean cooling value, the horizontal scale point on figure 12 is determined at 350.

4. From skin temperature (33° C.) is subtracted the mean air temperature (13.9° C.) to obtain the vertical scale point at 19.1.

5. Following the 350 diagonal line to its point of intersection with the 19.1 temperature line, the insulation value is found to be slightly above 1 clo.

Thus it is possible, within reasonable limits, to estimate the insulation values which would be required at any geographic location, at any time of the year, under any conditions of physical activity and physiological operation. Knowing the properties of fabrics, the insulation values and general potentialities of clothing types, and the specific circumstances of operations, it should be possible scientifically to provide a favorable environment for the body by means of clothing.

CHAPTER VI

MAJOR TYPES AND PROBLEMS OF CLOTHING

Clothing, as has been said, promotes the efficient and comfortable functioning of the body under varying conditions by (1) protecting it from heat, cold, water, fire and injury, (2) mitigating climatic factors and (3) aiding in the maintenance of dynamic body-heat balance. In brief, clothing establishes an immediate environment about the body which is more conducive to its functioning than are external conditions.

Protection from heat.—Under tropical and desert conditions a wide variety of factors must be considered in the determination of clothing requirements. They include temperature, humidity and wind velocity, type of work, solar radiation and salt and water loss.

Vaporization is the major channel of heat loss for the body under these conditions. Free ventilation of the skin is essential to promote cooling by the evaporation of perspiration. Dissipation of heat from the skin usually takes place more rapidly from uncovered portions of the body. On the other hand, clothing often helps to increase heat loss through evaporation and decrease heat gain by radiation and convection.

When effective temperatures are around 90° (dry-bulb temperature very high, 110–120° F.; wet-bulb well under 90° F.; humidity below 20 percent, see discussion of effective temperature and fig. 3), as for example in firerooms, evaporation may be increased materially by the use of close-fitting

elastic cotton underwear covering as much of the body surface as possible. When a man is stripped to the waist, most of the excessive perspiration runs off his body and is therefore not available for evaporation. This excessive perspiration is absorbed by a cotton garment and distributed uniformly over the entire surface by capillary action. A larger amount of perspiration is thereby vaporized more uniformly.

As a general rule hot-weather garments should be loose, thin and lightweight. The neck should be open, the sleeves and trouser legs short. Constriction at the trunk may be avoided by shorts buttoned to the shirt, or by suspenders when a coat is worn. Longitudinal slits under the arms of shirt and coat promote ventilation and are visible only when the arms are raised. Heavily starched clothing is impervious to air and should be avoided. Underclothing is desirable even for persons with scanty perspiration.

The shorts and shirt officially designated by the U. S. Navy for general tropical wear afford little protection from insects, scratches and abrasions or from flash burns. Standard undress whites, often worn without the jumper, also result frequently in serious sunburn. Men on watches, at guns and on lookout posts should be thoroughly protected on head and body.

Jungle fighting in the Pacific area has clearly demonstrated the necessity of long trousers and sleeves for all types of operations. Apparently, however, as compared to shorts, long trousers of similar material increase body heat only insignificantly.

Malaria control throughout most of the combat zones may be materially furthered, along with all other methods, by the wise utilization of protective clothing. "Protective clothing" in this instance simply means over-all covering of whatever nature. The British, for example, who favor shorts for desert action, have provided them with deep hem

flaps which can be turned down and tucked under the stockings for protection from insects at night.

The color of hot-weather clothing affects substantially the amount of solar radiation that will be absorbed. White generally will absorb the smallest amount of radiated energy, black twice as much. Stitt (*24*) reports experiments made by Grabham and Khartoum which indicate that when the air temperature is 45° C. (113° F.) in still air under bright sunlight, the temperatures under one thickness of cloth for several colors and types of fabrics are as follows:

Color and fabric	*Degrees C.*
Black, wool serge	83.0
Dark blue, cotton	79.2
Khaki, heavy, washed	76.0
Khaki, thin	72.3
Pale blue, old cotton	72.2
White duck, linen	61.9
White drill, washed cotton	59.5
White drill, cotton, new	57.6
Surrounding air	45.0

It will be noted that light blue compares favorably with khaki and white. Blue denim or chambray work outfits may therefore be especially practical under active operating conditions.

The best interests of hygiene in the Tropics are served by clothing that cannot only be readily and repeatedly washed but also be sterilized or disinfected by boiling. Parasitic skin diseases are very prevalent in the Tropics, and it is regarded as next to impossible to cure those caused by molds or mites without thorough and repeated disinfection of all clothing coming in contact with the infected skin.

Care must be taken to protect against sudden or considerable changes in temperature. After prolonged exposure to constant heat, the body becomes extremely sensitive to such changes.

Acclimatization to heat.—The importance of prior acclimatization of troops shifted from their native climates to tropical areas has been pointed out. Recent experiments have shown that subjects who have not had an opportunity to acquire a heat tolerance become completely exhausted after 1½ hours of hard work, developing an extremely high body temperature and rapid pulse. After acclimatization the subjects were able to perform the same tasks for 4½ hours without undue effort and with only moderate elevation of temperature and pulse rates.

Heat generated by the body under physical stress must be dissipated either by radiation or by the evaporation of sweat. If the temperature of the environment is higher than that of the body, as it often is in the Tropics, no radiation of heat from the body is possible; in fact, heat is absorbed. Sweating therefore is the body's main cooling device. The rate of water loss of perspiration can be increased about 23 percent by appropriate acclimatization procedures, with consequent reduction of salt concentration in the sweat to one-half its previous level. This is of great physiological value, inasmuch as loss of salt from the body leads to some of the important symptoms of heat exhaustion (fig. 2).

Men who already are in good condition for work in cool climates can be reasonably well prepared for work in the Tropics by 1 week of training in the heat, and well prepared by 3 or more weeks. About 80 percent of the improvement is found to occur in the first 7 days of training. Artificially produced acclimatization is well retained by the body for 2 or 3 weeks after the exposures to heat are discontinued, but tends to drop rapidly thereafter.

Based on the experiments cited and on recommendations of the Sub-committee on Tropical Diseases of the Division of Medical Sciences of the National Research Council, the U. S.

Naval Medical School suggests the following practical steps in artificial acclimatization:

1. If time is available and the season is suitable, troops destined for service in the Tropics should undergo a month of vigorous work in summer heat just before sailing.

2. If time is short and the season is unfavorable, equally good results can be secured by having the men do hard work 1½ to 2 hours daily for 3 or 4 weeks in a building with controllable temperature and humidity as follows:

Simulating average tropical climate—temperature 90° F., humidity 70 percent.

Simulating average desert climate—temperature 104° F., humidity 25 percent.

Merely having the men work for 1½ to 2 hours daily for 7 days in an artificially heated building will produce good results; or having them march for 7 days at 4 miles per hour on the level, or 3½ miles per hour on a 5-percent grade, long enough to raise body temperature and pulse rate and promote free sweating. If such daily exercises are found to be too exhausting, a rest day may be interpolated after the second and fourth work days.

3. Since most well acclimatized men tend to retain their condition for at least 3 weeks after stopping work, it is recommended that men during transit to a tropical combat area be given enough vigorous exercises each day to induce free sweating.

4. Since sweating depends on skin area, and since skin area per unit of bulk is greater in medium-size and thin individuals, there is theoretical objection to the stocky and large build for tropical work involving great physical stress.

Incidentally, with an extension of the wind-chill maps (figs. 7 and 8 and insert p. 22) to include iso-cooling lines for each month of the year, it should be possible to locate military training areas in the United States which closely

approximate conditions to be encountered in many foreign areas, thus obviating the necessity for artificial and time-consuming special operations.

Protection from cold.—Under cold conditions the function of clothing should be to establish an environment of optimal temperature immediately surrounding the body. Clothing serves to reduce the rate of heat loss from the skin by establishing an environmental constant, variable only in the degree of moisture absorbed in the clothing or in its permeability to air movement.

Siple (*22*) summarizes the practical factors of adjustment in this example:

Often individuals, after exposure to cold, come indoors temporarily to get warm without disrobing. They hover close to a heat source and proceed to absorb heat until complete warmth has returned and perspiration begins. Returning to the outdoors, the renewed warmth leaves their bodies with painful swiftness. Soon they feel chilled to the bone, commence to shiver, and are much more uncomfortable than before having gone indoors. Physiological events which occurred to produce this condition include:

1. Before coming indoors, stored body heat gradually had been lost until hands and feet were cold, although strong shivering had perhaps not yet started; the body was losing its stored and produced heat at its minimum rate of conductance because of vasoconstriction.

2. As warmth returned, the clothing began to absorb heat while the body began gradually to replenish heat in the cold skin. Soon skin temperature rose above 33° C. (91.4° F.), which signalled danger, as in a sense the body had "filled itself with heat" and was ready once again to concern itself with dispersing the excess heat.

3. Vascular dilatation took place in the skin and circulation increased as more and more heat became stored. Since the body was heavily clothed, heat could not escape and soon skin temperature rose to 34.5° C. and sweating began.

4. Before returning outdoors, the body had been conditioned to give off heat at least four times faster than it was doing at the time of coming indoors, while the clothing, damp from perspiration, was also transmitting heat at a slightly faster rate.

5. Outdoors again, the more exposed portions of the body began draining heat into the atmosphere with great speed over a steep temperature gradient. The pain of heat loss exerted on the cold sensory organs was intense, and in a short while drainage became so rapid that the body actually lost more heat (before vasoconstriction came into play and reduced the rate of loss) than it did before being warmed by the stove.

Another important point is that while exercising before coming indoors, during outdoor exercise, the body was producing about two or three mets of heat (100 to 150 kilogram calories per square meter per hour). While resting, the met production dropped to 1 (50 kilogram calories per square meter per hour). Therefore, upon exposure to air the body was reduced to one-third of its former production so that less heat was available in a system conditioned for rapid discharge.

If the pain incidental to these reactions can be withstood until the body can readjust itself, a fair degree of comfort will result, tempered to some extent by dampness in the clothing. There is no need, however, to undergo such discomfort and strains if a few reasonable rules, based on the principles of body heat balance, are observed:

1. Immediately upon coming indoors, shed outer, heavy clothing and gloves. Avoid yielding to the temptation of warming up rapidly by retaining all of the clothing insulation, especially if additional outdoor work is scheduled.

2. Avoid sweating; it will dampen clothing, thus increasing heat loss when again exposed to cold.

3. Stay indoors only long enough to regain minimal comfort; too long exposure to heat will upset body balance when again under cold conditions.

4. If hands and feet are cold, a change to dry gear will afford considerable relief.

Three layers of clothing are involved in cold weather protection: the underwear layer, the insulation layer and the wind- and water-resistant layer. These are well illustrated by the Navy's winter clothing issue shown in figures 13 and 14.

13. The Navy's special winter clothing for severely cold weather.

14. For wet and windy weather these garments are worn over the special winter clothing shown in figure 13. (Outfits from Bureau of Ships; photographs by Bureau of Aeronautics.)

Underwear is one of the most important elements of cold weather clothing. It serves as a heat filter to slow down radiation and convection and to conduct moisture away from the body. Underwear should be form-fitting, moderately dense, absorbent, lightweight, soft but with sufficient body to withstand compression. One-piece woolen underwear is preferred since it absorbs a large amount of perspiration, keeps the body relatively dry, eliminates double insulation at the trunk and is more comfortable. An example of the vital importance of wool underclothing is that of survivors of torpedoed vessels picked up in cold areas. In general only those wearing woolen underwear or who were heavily clothed survived.

The 10 percent body heat liberated through insensible perspiration can be turned to positive use during short exposures provided woolen underwear is worn. Once vapor concentration reaches 100 percent, however, real moisture will accumulate and the cooling rate will increase because of the high heat conductivity of water. Thorough drying of all woolen clothing, especially underwear and socks, increases its efficiency and prevents about 10 percent of heat loss in still air. Frequent changing of garments and the practice of drying at night the underwear used during the day are especially helpful.

Insulation involves usually normal clothing plus special outerwear. Wool is probably the most economical and generally efficient cold-climate clothing insulator. Loosely woven garments, however, are less durable, more shrinkable, less permeable to air, and are subject to distortion. Compromises are in order, but whenever possible first consideration should be given to lightness of weight combined with proportionate warmth.

Figure 13 shows the Navy's present dry-weather winter outfit. The blue jungle-cloth, wool-lined, over-all-

type trousers are sufficiently large to go over the usual clothing plus a special wool undergarment. A similarly constructed jacket closes by zipper and is kept tight at wrists and neck by knitted bands. The feet are protected by heavy knee-length wool socks and by arctics. Hands are covered by leather one-finger gloves which should be supplemented by wool inner gloves in very cold weather. The head is covered by a fleece-lined jungle-cloth helmet fastening under the chin and having a neck-guard. In severe wind, a face mask and goggles are also worn.

Care must be exercised not to overdress because body heat production increases with activity. Perspiration should always be avoided. The body is unable to check the flow of water to the skin surface when skin temperature rises to about 34.5° C. The resultant flood of moisture dampens the clothing and tends to cool the body by added conduction; this cooling will continue after the need for sweating has ceased. Personnel exposed to cold conditions should learn to estimate their clothing needs in terms of environmental conditions and expected degree of activity. They should as a general rule attempt to underdress rather than overdress for quiet conditions, and be prepared to take immediate steps to facilitate cooling by increased ventilation when body heat rises above the comfort level. This may usually be accomplished by baring the hands, which act much as an automobile radiator in cooling.

Wind and water resistance normally is a function of a third clothing layer. Approximately 75 percent of potential heat loss from the body may be due to an increase in air movement as was shown in figure 4. The most effective means of reducing this loss is by creating a shell which is more or less impervious to wind. A long-staple cotton fabric of dense weave is the most efficient fabric for this purpose, al-

though of course it affords little protection against radiation and conduction loss.

A windproof garment reaches optimal efficiency with a combination of thin pliability, minimum weight and a density just short of being impervious to moisture. The Navy's wind- and water-repellent shell for cold conditions is shown in figure 14. The trousers and parka-type jacket are made of very tightly woven material, which while not waterproof in the same degree as oilskins, is far more satisfactory because the material "breathes" (allows body moisture to be transmitted outside). At the same time it breaks the force of the wind and prevents water from saturating the insulative layers of garments. A windproof garment may be made water-repellent but should never be made waterproof, because water of perspiration will accumulate in large quantities inside waterproofed clothing.

Aviation Clothing

Clothing for the aviator involves most of the problems associated with general heat and cold protection, as well as many more peculiar to aircraft operations. The latter include weight, bulk, resistance to flame, floatation, ease of putting on or taking off, integration with equipment, protection against temperature extremes, degree to which the outfit limits normal activity, and protection afforded when the wearer is forced down.

The effect of altitude has been discussed. For example, in going from sea level to 30,000 feet, an aviator will encounter a temperature drop of approximately 105° F. That is, he has progressed, let us say, from a ground temperature of 70° F. to minus 35° F. at 30,000 feet. Ground temperatures encountered by air crews may vary from minus 60° F.

15. Navy pilot's lightweight summer coverall is essentially a wind "shell" worn over normal clothing.

in northern Canada and Alaska to 120° F. or more in tropical regions. Add to this the fact that the temperature of the interior of a metal aircraft standing in the tropical sun may be as high as 140° F. In many instances the air crew must climb into an aircraft under these conditions clad in outfits which will protect them from the extreme cold of high altitudes and do this within a relatively few minutes.

Engineering developments and conditions of warfare have also profoundly changed aviation clothing requirements. Peacetime air operations usually involved lower altitudes, required less mobility on the part of the crew, and were not concerned with the imponderables of enemy action. The current trend to increased ranges and higher altitudes may reveal new clothing problems.

In general it may be said that present clothing has been successful in a degree inversely proportional to the duration of the flight. For example, the operation of a long-range bomber which will be aloft in extremely low temperatures for many hours requires clothing that will protect for the entire period during which some crew members, as the turret gunners, will not be able to move to any appreciable degree. The effect of such prolonged cold may be not only to put the gunner out of action on the present mission, but also to render him unavailable for a considerable period because of both physical and psychological reactions.

Aviation clothing has been developed from three main concepts:

1. *Heating the airplane cabin.*—This method offers the advantage that adjustments can be made to environmental changes, and personnel are not hampered by heavy clothing. Heating arrangements may be practical for patrol, transport and passenger carriers, but also to be considered in war are the effect upon plane and crew of enemy action and the results if the heating system should fail or the plane be

16. Navy aviator's mediumweight leather jacket is worn with regular blue denim work trousers.

forced down on cold terrain with the personnel unprotected. The low heat content of rarefied air poses other problems. Condensation of moisture or frost on window surfaces hampers visibility, but the walls of the plane compartments must be kept warm to prevent too great a heat loss by radiation from the men's bodies. Further development of the pressure cabin plane, where increased air pressure can be utilized to provide warmth, would seem at present to be the solution.

2. *Unheated insulative clothing.*—This has long been the mainstay of flight crew outfits, its chief advantage being the independence afforded each crew member from all outside heat sources under all conditions, including forced landings on cold terrain. Two main difficulties are involved, however. It is often difficult to adjust the amount of clothing worn to the amount required by widely varying conditions. Especially is this true in the case of the pursuit pilot who must don clothing on the ground, sometimes at very warm temperatures, which will protect him at high-altitude temperatures. Perspiration accumulates at ground-level temperatures, rendering the garment uncomfortable and inefficient when cold is encountered.

Another difficulty is the bulk of insulative suits because weight and bulk may seriously interfere with the task at hand. Shearling, which is sheepskin with the wool side turned in, has long been a basic material for aviation suits. In actual service it has the disadvantages of excessive weight, bulkiness, stiffness, relative impermeability to water vapor and difficulty in drying because the outside is coated for durability. Other types of manufactured cloth, such as cotton and wool pile, seem to be equally as effective insulators and in addition enable the wearer to move about with more freedom. These latter materials "breathe."

A fighter pilot desires freedom of movement even if he gets cold. The best padded suits currently in use, for all

17 (A). Aviator donning the standard heavy insulative flying outfit.

17 (B). The Navy standard aviation two-piece outfit for normal high-altitude flying.

their bulk, are only four or five times as warm as ordinary clothing and protect at best for approximately 6 hours in around 20° F. Below this temperature and for longer periods body heat production must be increased. This process is complicated by the fact that it necessitates an increase in oxygen consumption, but being in confined quarters it is not possible for all air crew members to exercise to the extent necessary to maintain heat balance.

The effect of fatigue with resultant slower reaction-time must also be considered. With a temperature decline of 1° C. the body gives up as much heat as is produced by it in three-

quarters of an hour at a resting rate of metabolism. Any unusual temperature fall in the body is undesirable because of the discomfort and decrease in efficiency which may be expected. Drowsiness will likely follow upon return to lower, warmer altitudes.

3. *Heated clothing.*—This permits reduction in bulk and protects against extremely low temperatures. Heat may be supplied either by circulation through the suit of air warmed by the engine, or by means of an electrical inner lining with energy taken from the plane's power plant.

Electrically heated clothing appears to hold much promise when used with varying amounts of insulative clothing. Certain limitations of this type should be noted, however. Inadequate protection is afforded in case of failure of the power supply, or in case of forced landing and abandonment of the ship on a cold terrain. A substantial amount of electrical energy is needed for each suit at extremely low temperatures even when only moderately insulative clothing is used. In the case of air heating there is danger of carbon monoxide poisoning. In both types aviators balk somewhat at the necessity of external connections between their clothing and the plane.

Also the physiological factors normally responsible for heat balance in the body may be upset to such an extent by external application of heat that they cannot be depended upon to issue their normal warnings in connection with body temperature control. The individual's sense of comfort cannot, therefore, be entirely relied upon as respects proper adjustment of heating mechanisms. For this reason proper distribution of heat to various parts of the body is of fundamental importance.

It is apparent that clothing, particularly aviation clothing, is increasingly a subject for medical consideration. For example, a large naval air station in the southern United States

18 (*A*). Aviator donning the electrically heated flying outfit of the Navy.

18 (*B*). Air crewman fully attired in electrically heated aviation suit.

NOTE: All aviation clothing photographs were furnished by the U. S. Naval Air Station, Anacostia, D. C.

reported recently that on a typical day of record, 198 persons in flight status were grounded for medical reasons. Of 77 men hospitalized, 32.5 percent were incapacitated by upper respiratory infections. Of 121 grounded at the dispensary but not requiring hospitalization, 66.9 percent were for upper respiratory infections. A material percentage of such illnesses and resulting flight time loss could be prevented by the proper use of effective protective clothing.

Figures 15 through 18 illustrate the several main types of aviation clothing currently in use by the Navy. The standard, heavy, insulative flying outfit (fig. 17 (*A*)) has suspender-

type trousers made of shearling fastened by zippers and worn over regular clothing. Fleece seals at ankles and waist merge into similar linings of the boots and jacket to provide a cold-proof seal. The complete, standard, two-piece outfit (fig. 17 (*B*)) is regulation for normal high-altitude flying. Boots are equipped with a special zipper release for quick removal if the flyer is forced down in water. The outer skin of the shearling is coated and impervious to air. However, with the wool lining and with woolen underwear, a considerable amount of perspiration may be absorbed, largely overcoming the disadvantage of the outfit's bulkiness. The outfit represents probably the maximum bulk consistent with efficient operations. The electrically heated flying outfit (figs. 18 (*A*) and 18 (*B*)) is used in extreme cold conditions and for long-range high-altitude flying. The suit is one-piece, of coated leather, with an inner lining containing the heating grid. Gloves of the five-finger type connect into the heating circuit by means of two snaps.

CHAPTER VII

SPECIAL CLOTHING PROBLEMS

Protection of the extremities is more difficult than protection of other parts of the body, yet adequate provision must be made for them if total body protection is not to be undermined. Thermal insulation requirements for different areas of the body vary considerably. For example, while the temperature of the trunk is 80° F., the temperature of the toes may drop to 40° F. If hands and feet are maintained at slightly higher temperatures than the rest of the body, a vasodilatation takes place which produces excessive sweating over the whole body, thus increasing heat loss and producing considerable fatigue after several hours. From data compiled by Siple (*23*) the following principles for keeping the feet warm may be summarized:

1. Keep the feet dry; foot coverings for use in temperatures above zero (Fahrenheit) and under wet conditions are usually snug-fitting and waterproof. Perspiration is of secondary consideration since there is little danger of socks freezing. One or more pairs of woolen socks, preferably ribbed for greater elasticity, will take care of insensible perspiration. Socks should be thoroughly dry before they are put on. As an outer foot covering the standard Navy arctic (figs. 13 and 14) is satisfactory.

2. Under extremely cold, dry conditions (below 0° F. with a slight breeze) precautions change from an attempt to keep moisture from entering footgear to an attempt to conduct moisture outside or to facilitate absorption within. Thus oil-tanned or otherwise waterproofed shoes and boots are

contraindicated. Experience in the polar regions, as well as the customs of Russians, Canadians, Eskimos and other northern peoples, tends to prove the efficacy of dry-tanned leather, felt, burlap and similar materials. Most successful is the Eskimo mukluk. The sole and toe of the mukluk are made of a dry-tanned leather which remains flexible in the coldest weather; the upper, about 12 inches long, is of burlap. This is worn over two or more pairs of woolen socks, and between each pair is a felt inner sole. The mukluk is held in place by means of strings loosely wound around the leg and tied above the calf. Under wet conditions a waterproof boot may be substituted.

3. In cold climates it is essential that footgear be large and roomy. Any constriction will cause a decrease in the blood circulation, and circulation is of course the principal means of maintaining body heat in the feet.

4. Feet are especially subject to freezing. As long as they can be moved easily and the sensation of cold is acute, freezing has not yet set in. If cramping prevents movement of the toes, and if pain of great intensity lets up without good reason, the feet should be examined promptly. Circulation arrested by freezing or frostbite can be restored by placing the affected parts next to warm flesh. Never treat by rapid heating near a stove, immersing in cold water, rubbing with snow, or any brisk, abrasive rubbing. Such treatment tends to aggravate the condition and to abrade the skin, thereby setting up conditions conducive to infection. Frozen toes should be cupped in warm hands, and alternating gentle pressure and release of pressure should be applied until normal circulation has been restored.

Hands are sometimes more difficult to protect than any other parts of the body. Airplane pilots and gunners, for instance, must have a high degree of flexibility in their

fingers. A few minutes of exposure while taking an astral sight at minus 20° F. is sufficient to cause frostbite. In general the multiple-layer principle (short of electrical heating) seems most advantageous, since insulation may be varied with temperature and task.

Basic principles for protecting the hands under cold conditions are similar to those for the feet:

1. Avoid lengthy exposure. Do not touch metal, snow or ice. Keep the wrists, palms, and backs of the hands covered as much as possible.

2. Wear loose-fitting woolen mittens, with separate wind-impervious coverings. Do not wear gloves that separate the fingers because radiation between the fingers is an important source of heat.

3. Chilled hands often are the result of overheating the rest of the body, or they may be caused by constriction which prevents proper circulation of the blood. Avoid garments that fit tightly around the upper arm or under the armpits where large blood vessels come near the surface.

4. Keep the hands and handgear as dry as possible because moisture increases conductivity. Changing to dry mittens when hands and mittens are wet and cold will immediately produce a feeling of warmth.

5. Freezing of the hands is treated as described for the feet, i. e., gently massaging with warm hands to stimulate circulation, or placing the hands on warm flesh under the armpits, between the thighs or on the abdomen.

The head, particularly the face, is able to withstand a greater change in external climatic conditions than the body as a whole. The vital areas to be protected in their probable order of necessity are:

1. The ears, because of their thinness, poor circulation and exposed location are susceptible to quick, painful freezing.

Even in moderately cold weather earmuffs are indicated even though the rest of the head may be uncovered.

2. The back of the neck must be protected because of the vital sensory nerve cords and the tendons which lie close to the surface in this location. The temples, forehead and throat must also be protected because of their superficial blood vessels.

3. The top of the head, when a normal amount of hair is present, will be safe without covering in temperatures as low as about zero degrees Fahrenheit provided no wind is blowing, although a light head covering is always preferable. Air crew personnel can usually keep their heads sufficiently warm even under severe conditions by wearing an outer leather helmet over the cloth or knitted inner one (figs. 15 through 18). The chief problem is to provide comfortable support for earphones, microphone, oxygen mask and goggles.

4. The chin will withstand a considerable range of temperatures, but when the wind is strong it requires protection as do the nose and cheeks. The mouth and eyes are, however, more difficult to protect, and complete face masks (as shown in figs. 13 and 14) must be used in severe weather.

5. The eyes offer special problems. Snow blindness is particularly serious. No matter how strong the eyes may be, they are susceptible to snow blindness and perhaps permanent injury unless suitable precautions are taken. Snow blindness is caused not only by the glare of direct sunlight on snow, but also by diffused light on a cloudy day. Polaroid glass does not help as light is reflected from many planes. The goggles issued with Navy winter clothing (figs. 13 and 14) are, however, suitable for cold weather use. The anti-flash eye-shield in amber color (fig. 20) has been used also under tropical conditions.

6. Freezing of the flesh about the face or head may proceed so quickly as to be unnoticed. At the moment of freezing a sharp twinge of pain shoots through the affected part and it suddenly turns white. There is an unwritten law in cold countries that each man will call attention to his companion's face whenever he sees these characteristic white areas.

Protection against gas, flame, flash.—Gas-protective clothing usually consists of an impregnated over-all covering worn with impregnated woolen socks, gloves, rubber overshoes and a gas mask. In emergency almost any type of clothing which covers the entire body and is of relatively close weave may usually be impregnated fairly successfully.

Efficient flame-resisting suits which enable damage-control measures to be taken promptly and effectively are necessities on most ships. The Navy's present fire-protection equipment is illustrated in figure 19. It should be noted that the rescue breathing apparatus is worn on the *outside* of the suit. The rubber facepiece of the apparatus should be worn under the hood of the suit, with the corrugated breathing tubes protruding through the hole in the hood, and the bag worn on the outside. When the breathing apparatus is not used, an asbestos flap covers the hole in the hood. The suit is considered indispensable in fire fighting for gaining access to compartments under severe fire conditions and for taking damage control measures. This outfit is light, having no wire inserts, and for practical purposes is entirely fireproof.

A major and relatively new type of casualty which has made its appearance in World War II is "flash burn" from exploding bombs, explosions and fire. Such burns were of primary concern after the Pearl Harbor attack and have since been prominent in nearly every action. The extent of burns is directly related to the covering afforded the body by clothing because the injury is caused by a sudden, instan-

19. The flame-resisting suit of the Navy. (Photograph from Bureau of Ships.)

20. Antiflash protection is currently afforded by this outfit. (Outfit from Bureau of Ships, photograph by Bureau of Aeronautics.)

taneous but intense wave of radiant heat, not by prolonged intense heat or actual flame. Thus short-sleeved shirts, open collars and shorts are definitely contraindicated.

Flash burns at first sight rarely seem serious, appearing to be merely a slight searing of the skin. However, several hours after the blast the victim is usually found to be suffering from severe physical shock. He may lose control of the injured parts, and occasionally death occurs.

The Navy antiflash outfit is shown in figure 20. It consists of elbow-length gauntlet-type gloves, gathered at the top, a hood made of lightweight cotton, a stiffened gauze "bib" to protect the mouth, and a plastic eye-shield. Any type of other clothing may be worn, providing all areas of the body are covered. In action all personnel should be so protected. The British—whose outfit is essentially similar and in fact is the forerunner of this one—report that in spite of the discomfort naturally associated with the outfit, little difficulty is experienced in enforcing its use, especially with personnel who have seen action. American experience has apparently not followed this pattern. Care should be taken to see that clean outfits in good order are always available for instant use by all members of the crew when they are to be exposed to flash.

In the development and use of clothing of all types, as has been pointed out, a nice balance must be maintained between elements relating to the physiological functioning of the body, needs of the environment and practical tasks. Antigas and antiflash outfits are cases in point. Experience has disclosed at least two major problems: Ammunition parties and gun crews suffer considerably from heat when wearing antiflash gear, and occasionally from skin disease caused by wearing dirty flash helmets.

Fighting vigor is definitely inhibited by heat. At effective temperatures in the range of 80° to 90° any gear which tends to increase body heat or decrease operating efficiency must be questioned. Antiflash outfits made of lightweight material probably should be considered. Or perhaps a combination of clothing for general body protection and the use of a medicated ointment for the face and hands will prove to be adequate protection.

CONCLUSIONS

1. Protective garments should not be designed without specific regard to their physiological effect upon the human body. To further this end, a close liaison between those concerned with physiology, physics, clothing design and construction, and the field use of the gear is indicated. Further, information and experience is desirable between the various groups involved with these problems in the United Nations.

2. Research and field experimentation should be encouraged. The work of Siple and the Army Quartermaster and Air Corps, of the several experimental laboratories, and of the National Research Councils of Canada and the United States is to be commended.

3. There is need in the military services for practical application of the fundamental principles of clothing requirements described here. Many apparent "failures" of clothing equipment are largely due to faulty use in the field. An extensive educational effort is indicated (*a*) for line and medical officers in the fundamental concepts of clothing and their practical application, (*b*) for personnel in the proper uses of clothing gear, and (*c*) for all personnel and especially air crews in an attempt to increase confidence in the equipment.

BIBLIOGRAPHY

1. Macleod, J. J. R.: Macleod's Physiology in Modern Medicine. Ed. by Bard, Philip. 9th ed. The C. V. Mosby Co., St. Louis, Mo., 1941.
2. U. S. Navy Department, Bureau of Medicine and Surgery: A Manual of Naval Hygiene. U. S. Govt. Printing Office, Washington, D. C., 1943. Pp. 4–31.
3. Boyd, Mark F.: Preventive Medicine. 5th ed. The W. B. Saunders Co., Philadelphia, Pa., 1936.
4. Burton, A. C.: Application of the theory of heat flow to the study of energy metabolism. J. Nutrition 7: 497–533, May 1934.
5. Du Bois, Eugene F.: Basal Metabolism in Health and Disease. 3d ed. Lea and Febiger, Philadelphia, Pa., 1936.
6. Du Bois, E. F.: Lane Medical Lectures: Mechanism of heat loss and temperature regulation. Stanford Univ. Publ., Univ. Series. M. Sc. 3: 323–407, 1937.
7. Du Bois, E. F.: Heat loss from the human body; Harvey Lecture. Bull. N. Y. Acad. Med. 15: 143–173, March 1939.
8. Ferderber, M. B., and Houghten, F. C.: Effective temperature scale; a measure of human comfort in environmental temperature. J. A. M. A. 116: 474–477, Feb. 8, 1941.
9. Gagge, A. P.; Burton, A. C.; and Bazett, H. C.: A practical system of units for the description of the heat exchange of man with his environment. Science 94: 428–430, Nov. 7, 1941.
10. Gatewood, James Duncan: Naval Hygiene. P. Blakiston's Son & Co., Philadelphia, Pa., 1909.
11. Hall, G. E.: Aviation medicine in the Royal Canadian Air Force. J. A. M. A. 119: 1104–1107, Aug. 1, 1942.
12. Hardy, J. D., and Du Bois, E. F.: Basal metabolism radiation, convection and vaporization at temperatures of 22° to 35° C. J. Nutrition 15: 477–497, May 1938.
13. Houghten, F. C.; Ferderber, M. B.; and Rosenberg, A. A.: Physiologic effects of hot atmospheres. Indust. Med., Indust. Hyg. Sect. 1: 7–17, Jan. 1940.
14. Howell, Wm. H.: A Text-Book of Physiology for Medical Students and Physicians. 13th ed. The W. B. Saunders Co., Philadelphia, Pa., 1936.
15. Kleiber, M.: Nutrition (energy metabolism); in Annual Review of Biochemistry. vol. 6. Ed. by Luck, James Murray. Stanford Univ. Press 1937.

16. Lusk, Graham: The Elements of the Science of Nutrition. 4th ed. The W. B. Saunders Co., Philadelphia, Pa., 1928.
17. Mann, W. L.: Field sanitation. U. S. Nav. Med. Bull. 36: 327–412, July 1938.
18. Pinson, E. A., and Benson, O. O., Jr.: Problems inherent in the protection of flying personnel against temperature extremes encountered in flight. J. Aviation Med. 13: 43–52, Mar. 1942.
19. Pryor, James Chambers: Naval Hygiene. P. Blakiston's Son & Co., Philadelphia, Pa., 1918.
20. Royal Canadian Air Force Manual of Winter Operations. Govt. Printing Office, Ottawa, Can., 1943.
21. Saxl, T.: Burns en masse. U. S. Nav. Med. Bull. 40: 570–576, July 1942.
22. Siple, Paul A.: General principles governing selection of clothing for cold climates. U. S. Antarctic Service. To be published.
23. Siple, Paul A., and Passell, C. F.: Measurement of dry atmosphere cooling in sub-freezing temperatures. U. S. Antarctic service. To be published.
24. Strong, Richard P.: Stitt's Diagnosis, Prevention and Treatment of Tropical Diseases. 2 vols. 6th ed. P. Blakiston's Son & Co., Philadelphia, Pa., 1942.
25. U. S. Navy Department, Bureau of Medicine and Surgery: Handbook of the Hospital Corps. U. S. Govt. Printing Office, Washington, D. C., 1939.
26. U. S. Naval Medical School, National Naval Medical Center: Tropical and Exotic Diseases of Naval Importance, Notes on. Nov. 1942.
27. White, Gladys: Personal communication.
28. Winslow, C-E. A.; Gagge, A. P.; and Herrington, L. P.: Heat exchange and regulation in radiant environments above and below air temperature. Am. J. Physiol. 131: 79–92, Nov. 1940.
29. Winslow, C-E. A.; Herrington, L. P.; and Gagge, A. P.: Relations between atmospheric conditions, physiological reactions and sensations of pleasantness. Am. J. Hyg. 26: 103–115, July 1937.
30. Yaglou, C. P., and Miller, W. Edw.: Effective temperature with clothing. Trans. Am. Soc. Heating and Ventilating Engineers 31: 89, 1925.

○